Firefighting Strategy and Leadership

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To Cath

Preface

Firefighting, a necessary activity wherever men live and build structures, is fundamentally a science, since it is founded upon principles and laws capable of quite definite statement. Just as fundamentally, it is also an art demanding skill, ingenuity, experience, and judgment. This book aims at helping firemen and fire officers of all ranks, paid or volunteer, evolve such a science and develop such an art.

No attempt is made to cover the elementary knowledge or training—in the use or care of equipment, for example—given by all fire-service organizations to their recruits. Instead, I have tried to show how these basic skills should be applied—to explain when and where to do what, and why.

Firefighting is a critical occupation in which the community at large, the fire department, and the individual fireman have vital stakes. The welfare, and indeed the lives, of many persons are daily entrusted to the firefighter, and his work is attended by considerable personal danger. Delay, confusion, and poor judgment can have appalling consequences.

For these reasons, I have concentrated on firefighting strategy (or art) and leadership—a strategy that stresses use of the same mental approach for evaluating and solving problems at all types of fires rather than a separate approach for each type of fire, and a leadership that suggests a venturesome and progressive spirit about the application of principles of management—particularly those related to *modern* concepts of leadership, discipline, morale, and command.

The fundamental nature and behavior of fire—how it spreads and how it may be extinguished—are considered in Part 1. The science of flame and combustion underlies all firefighting activities, but only in comparatively recent years have these matters been subjected to laboratory examination; the important principles that have emerged are still not as generally understood as they should be.

In Part 2 I have explained what the major problems and objectives of a firefighting operation are, how such objectives can best be achieved, and how individual elements such as building construction, location of the fire, or duration of the fire can complicate or simplify essential activities. The approach suggested here is designed to systematize sizing up any fire situation and aid the reader to construct his own diagnosis and determine the most pressing needs in proper order.

In Part 3 the emphasis shifts to the offensive. The reader is here prepared to respond to an alarm. He is aided in this by his increasing familiarity with the functions of various fire-service units and the principles governing these functions. Initially he may be surprised, but eventually it will be of benefit to him, to learn that the principles applicable to placement and use of lines, to ventilation, or to other functions are fundamentally the same in all fire organizations, large or small. He can then proceed to study the art of firefighting and how to develop it.

Part 4 is concerned with management, leadership, and the art of command. The day has passed when an officer could issue peremptory commands and expect blind obedience. Today's fireman is typically well-educated, alert, independent, and spirited. He can respond to the need for daring action in the finest traditions of the service—but he must first acquire confidence and trust in the leadership of his officers through their day-to-day routines and actions. Too little application of modern principles of direction and management has been made to the fire department, but in my opinion it is a greatly needed and immensely rewarding development. As these principles—in addition to those discussed earlier—are mastered, firefighting can achieve truly professional status.

Grateful recognition is due to the many who have contributed, directly and indirectly, to this work. In this group are members of all ranks and many fire departments. A special debt is owed to Joseph P. Redden, Chief Engineer of the Newark Fire Department, and John O'Hagan and Benjamin Powner, Deputy Chiefs of the New York Fire Department, for their reviews and helpful criticisms.

My thanks and admiration are also offered to an old friend and severe critic, Edward P. McAniff, Deputy Chief in the New York Fire Department. I have learned much from him.

Outstanding among the many nationally known publications reviewed during the preparation of this book were *Fire Engineering*, *Scientific American*, and literature of the National Fire Protection Association, the National Board of Fire Underwriters, the Gulf Publishing Company of Houston, Texas, and the Atomic Energy Commission. The "Principles of Management" by Koontz and O'Donnell was of special assistance.

Charles V. Walsh

Contents

PART 1

Combustion and Extinguishment

1

Heat and Flame

Recent scientific research has produced new knowledge and advanced ideas about heat, flame, and combustion. The physics of heat and flame involves problems in quantum mechanics and ultimately the question of the nature of the physical world. These problems are beyond the scope of this book, which is concerned with heat and flame only in their relation to firefighting. However, some results of recent scientific research are of interest to the firefighting service, and some scientific concepts are of importance to firefighters.

Heat—A Qualitative and Quantitative Concept

Heat can be considered mathematically and abstractly as *disordered molecular energy*. To understand this concept, we must appreciate that energy can exist in either potential or kinetic form. *Kinetic* energy is the energy of motion; it exists to some degree in all moving bodies. *Potential* energy, on the other hand, is the energy stored in a body that is under stress, compression, torsion, or pressure. It causes no motion of molecules and therefore is not directly responsible for heat that can be felt.

Potential energy may be converted into kinetic energy. For example, when a valve is opened, water under pressure begins to flow. When the uranium 235 atom fissions, potential energy is converted to kinetic.

Kinetic energy may be converted into heat. When the nucleus of a uranium 235 atom is struck by a neutron and fissions, the kinetic energy of the flying fragments is converted by collisions into random (disor-

dered) motions of the electrons and other atoms in the surrounding material, that is to say, into heat. Conversion of potential energy into heat is the working principle of nuclear reactors.

Heat is produced by adding energy to disorder, as when one compresses the air in a bicycle pump by pumping vigorously. The air heats up, causing the pump to become hot to the touch. The molecules of air still move randomly, but they are under greater pressure (have more energy). In consequence of the work done (pumping), more energy has been pushed into the system, and the observed production of heat is simply the effect of adding energy to the preexisting disorder.

Quantitative Measures of Heat. Two measures of heat are of interest here: a measure of the quantity of energy, and a measure of the quantity of molecular disorder.

Energy is measured by a practical unit called the *calorie,* which is the amount of heat required to raise the temperature of one gram of water one degree centigrade under standard conditions. The ultimate unit by which all forms of energy are specified is the *erg*, which is defined as the energy of a mass of one gram moving with a velocity of one centimeter per second. If one converts kinetic to heat energy, 1 calorie is found to equal 42 million ergs. Other important heat units are the large calorie (*Calorie*) and the British thermal unit (*Btu*). One *Calorie* is the amount of heat required to raise the temperature of 1,000 grams of water one degree centigrade. One Btu is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. One Btu is equal to 252 calories.

To measure molecular disorder quantitatively one must understand the concept of *entropy*. A detailed treatment of this concept is not appropriate here, but a brief mention is needed in order that certain points relative to heat and of interest to the fire service may be considered.

Entropy may be defined as a number that indicates the variety of ways in which atoms may be arranged in a system. Roughly speaking, entropy measures the number of degrees of freedom possessed by a system. (The word *system* refers to the quantity of matter under consideration. Everything else is spoken of as the *surroundings*. A *closed system* has no interchange between it and the surroundings, whereas an *open system* does have an interchange. *Process* refers to any change that the system may undergo.) A high-entropy system is free to be in many different physical arrangements. An example of such a system is a liquid: its molecules may arrange themselves in a huge variety of ways with regard to each other. An example of a low-entropy system is a crystal lattice: its molecules are arranged in a highly ordered way, and it is possible to know precisely which molecule goes where (Fig. 1-1). For the purpose of this book, entropy simply refers to the amount of molecular disorder in a system.

Thermodynamics is the science of the relation between heat and mechanical energy, or the study of changes in which energy is involved, and it is based on two simple but well-known laws. The law of conservation of energy states that the total energy, including heat, of any closed system remains constant. The second law states a kind of "conservation of disorder": the total entropy of any closed system must remain constant or increase as time goes on; it can never decrease. The tendency is for entropy to increase rather than remain constant.

The effects of the second law of thermodynamics are that heat is transferred in such a way as to increase entropy, that is, to increase the number of ways in which molecules of a substance may arrange themselves,

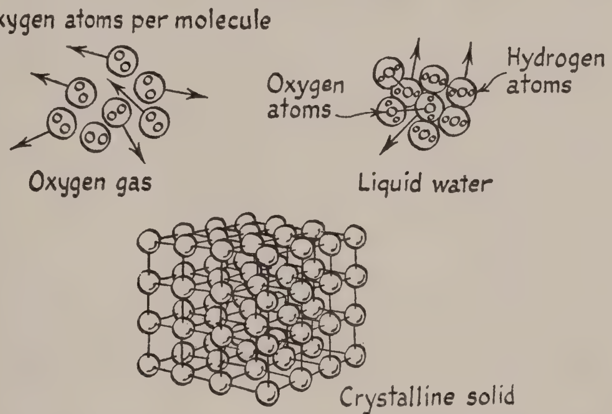

FIG. 1-1. Atomic patterns of matter in a liquid or a solid. (*From "The Neutron Story," by Donald J. Hughes, Anchor Books, Doubleday & Company, Inc., Garden City, New York,* 1959.)

and that heat must flow from areas of higher to those of lower temperature. As temperature drops, the amounts of energy and disorder both decrease. But the energy always decreases more rapidly than the disorder, so that the amount of disorder per unit of energy grows larger as the temperature falls. A given amount of energy carries more disorder at lower temperatures. Hence heat tends to move from a higher to a lower temperature, and, in so doing, each unit of energy acquires greater disorder (or entropy).

Heat Transfer by Radiation. Radiation is energy in the form of electromagnetic waves, which are traveling disturbances in space and which include light, heat, radio, and cosmic rays. Electromagnetic waves are produced by acceleration of an electric charge and include an electric field at right angles to a magnetic field, both moving at the same velocity in a direction normal to the plane containing the two fields. They behave like other forms of energy, except that they can exist in empty space in

the absence of matter. When electromagnetic waves are disordered, they convert to heat and are subject to the laws of thermodynamics.

The existence of heat radiation implies that no material body is ever completely isolated; the space around every object will contain radiation. If there is a temperature difference between the object and the radiation, energy will flow into or out from the object in order to equalize the temperature. Thus, by the process of radiation, energy is transferred from hotter to colder objects.

It is characteristic of radiation that the quantity of heat radiated from a given source varies as the fourth power of the absolute temperature, other conditions being equal. Thus, the quantity of heat radiated from a given source at 600°F compared with the same source (under the same conditions) at 500°F can be found by use of the equation

$$\frac{Q_2}{Q_1} = \frac{(600 + 459)^4}{(500 + 459)^4}$$

The rate at which a piece of matter can radiate away its energy is likewise related to temperature and varies as the fourth root of the energy for heat radiation. The practical effect of the fourth root is illustrated as follows:

If a piece of matter at 600°C can radiate away half its energy in one hour, the same piece of matter at 6000°C, having about (6000 + 273)°K divided by (600 + 273)°K, or 7.18, times as much energy, would radiate away half its energy $(7.18)^4$, or about 2,660, times as fast. Hence the half-energy emission would occur in 3,600 seconds × 7.18 ÷ 2,660, or 9+ seconds.

The escape of heat via radiation places a practical limit on flame temperature, which in fire areas may range from 3000 to 5000°F. However, effective temperatures, as measured by the melting of metals and other effects, have a practical upper limit of 3000°F, and they are usually less.

Heat may radiate downward from thermal columns bent over by the wind and traveling ahead of a conflagration. Such columns contain highly heated vapors in which actual burning is taking place. In some cases, radiation from such columns has caused ground fires well ahead of the conflagration. This explains why it is practically impossible to operate successfully ahead of or on the lee side of a conflagration.

The major portion of radiant heat passes through drops of water and through ordinary window glass (Fig. 1-2). The latter may intercept only about 15 per cent of radiant heat energy. This must be kept in mind by firefighters when covering or protecting exposures. It may be more appropriate to wet down exposures rather than protect them by water curtains (Fig. 1-3). It has been proved that much less radiant heat will pass through window glass that is kept wet, by a fog stream, for example.

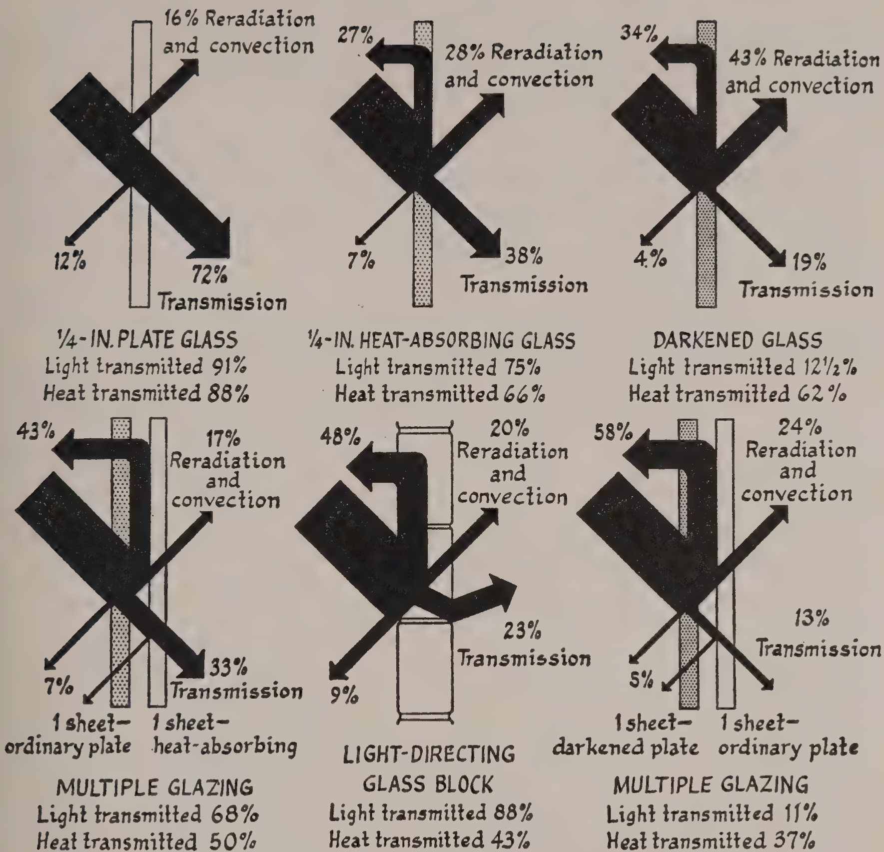

FIG. 1-2. Transmission of radiant heat through glass. (*From "The Contemporary Curtain Wall," by William Dudley Hunt, Jr., McGraw-Hill Book Company, Inc., New York*, 1958.)

FIG. 1-3. Protecting severely exposed structure against radiant heat.

Radiation is largely reflected from bright, smooth surfaces. This fact makes aluminized firefighting garments effective against heat radiation. Such garments protect the wearer by reflection rather than by insulation.

Heat rays are similar in many ways to light rays. Both travel in straight lines, at the same rate of speed, and spread out in all directions unless this pattern is disrupted by absorption or scattering, which may be the result of reflection and diffraction (or bending) (see below, Radiation in Nuclear Explosions).

In most instances, the fire service is concerned with radiation emitted from *point sources,* that is, from fires of comparatively small extent, at which the intensity of radiation will vary inversely as the square of the distance from the source. Hence, at 60 ft from the point source, the intensity of the radiation is one-quarter of that at 30 ft. This variation does not apply, however, when the source of radiation is *linear,* as exemplified by grass fires with a long front and flames of limited height. Here, radiation varies inversely as the distance (not as the square of the distance): at 60 ft from the linear source, the radiation intensity is one-half of that at 30 ft. When the fire source is an *area,* such as a forest or a lumberyard, where the fire is extensive with a high flame front, radiation intensity decreases with distance, but not in accord with the rules governing point and linear sources. At distances considered sufficiently large in comparison with the height and width of the flame front, the area source starts to resemble the point source in regard to the relation of intensity and distance. At intermediate distances, particularly near the area source, attenuation of radiation will be only slight.

The distance is the major consideration where structures are endangered by heat radiation. Consequently, proximity of exposures to the fire building in some cases determines the order of priority in covering exposures, despite the direction of the wind. The wind influences the situation, however, when it changes the direction of the convection currents so as to weaken or strengthen heat radiation intensity, by increasing or decreasing the distance the radiant energy must travel to the exposures. If hot surfaces are the source of radiation, the angles of emission from the source and of reception at the exposure affect intensity received. The intensity is greatest at the point opposite to the surface in a perpendicular direction as compared with other equidistant points. The fire service is more often concerned at fire operations with the effects of radiation emitted from convection currents than with effects determined by hot surfaces.

Much of the following treatment of heat radiation in nuclear explosions pertains to heat radiation in conventional fires.

Radiation in Nuclear Explosions. Fires caused by nuclear explosions present potentially stupendous problems to the fire service.

In a conventional (TNT) explosion, nearly all the energy is released as kinetic energy, which is immediately converted into blast and shock. In a nuclear explosion, however, about 85 per cent of the energy released is kinetic, of which only about 50 per cent is converted into blast and shock; the remaining 35 per cent is converted into heat and light rays. Furthermore, very high temperatures are involved (several million degrees, compared with several thousand degrees in a TNT explosion).

After a nuclear explosion, a large quantity of heat is radiated in a very short time. Consequently, the intensity of radiation, that is, the rate at which it reaches a particular surface, is very high. The heat is absorbed very rapidly, with very little time for it to be conducted away internally.

Heat-radiation intensity is reduced by absorption and by scattering, as well as by distance.

Atoms and molecules in the air can absorb, and thus remove, certain rays, particularly ultraviolet rays. Oxygen and ozone are important in this connection. Normally, the proportion of ozone in the air is quite small, but appreciable amounts are produced by the effect on atmospheric oxygen of gamma radiation from a nuclear explosion.

Scattering of radiation, that is, diversion of rays from their original paths, can be caused by molecules, of nitrogen or oxygen, for example, in the air or, more importantly, by particles in the atmosphere, such as dust, smoke, or fog. Radiation of all wavelengths can be scattered, with the energy attenuation varying with the wavelength. Visible light rays and the shorter infrared rays are more susceptible to attenuation by scattering, and by absorption, than are the longer infrared rays.

In the case of a nuclear explosion, a dense smoke screen between the point of the bomb burst and a given target can reduce the radiation received at the target to as little as one-tenth the amount that would otherwise be expected. Artificial white (chemical) smoke acts just like a fog in reducing radiation intensity. If the explosion occurs above a dense layer of cloud, smoke, or fog, an appreciable amount of radiation will be scattered upward from the top of the layer. This scattered radiation may be regarded as lost, as far as the ground is concerned. In addition, most of the radiation that penetrates the layer will be scattered; very little will reach a given point by direct transmission.

If the explosion occurs in moderately clear air beneath a layer of cloud or fog, some of the radiation that would normally proceed outward into space will be scattered back to earth. As a result, the radiation received on the ground will actually be greater than for the same atmospheric transmission conditions without a cloud or fog cover.

Objects may also be protected from radiation by shielding. Any solid opaque material, such as a wall, a hill, or a tree, between the bomb burst and an object will act as a shield against radiation. However, if atmos-

pheric conditions are hazy, much of the radiation will be scattered; consequently, it will arrive at an object from all directions and not merely from the point of burst. Shielding protection is greatest if the shield completely surrounds an object.

Even after radiation intensity has been reduced by absorption and scattering and by shielding, some radiation will reach a given target. When radiation reaches an object, part is absorbed, part may be deflected, and the remainder will pass through and ultimately reach other objects. It is absorbed radiation that produces heat in the object and causes damage. Highly reflective and transparent materials absorb little radiation and hence suffer little damage.

If much radiation is absorbed, organic materials (such as wood) may ignite. Ignition depends largely on thickness and moisture content: under the same conditions, a thin piece of wood may flame and a thicker piece only char. Although the surface temperature in the thicker piece may temporarily exceed the ignition point, the heat is rapidly transferred away by conduction, convection, and radiation: the temperature drops, and combustion eventually ceases (see below, Heat Transfer by Conduction).

Heat Transfer by Conduction. Conduction is the process by which heat is transferred within a material from one particle to another or from one material to another in contact with it, without any visible motion. Heat is conducted because faster-moving atoms, electrons, or molecules in the hotter part of an object induce activity in adjacent atoms, electrons, or molecules, and thus heat flows from the hotter to the colder parts. The amount of heat transferred by conduction varies with the conductivity of the material and the area of the conducting path. Thermal conductivity is the ability of a material to conduct heat away internally. In a given material, conductivity increases with density. Wood, for example, has greater density, and hence greater conductivity, when wet. Wet wood is less apt to ignite than dry wood when exposed to radiant heat, because heat is transferred more rapidly away from the igniting source. Consequently, sustained-combustion temperatures are less likely to be reached. Thermal conductivity is expressed in British thermal units per hour per square foot of surface per degree Fahrenheit of temperature difference of the surface per inch of thickness; it may also be expressed in metric equivalents.

It is important for firefighters to know the conductivity of various materials in order to determine the possible spread of fire and to prevent rekindles (Fig. 1-4). For example, heat conducted by metal beams may cause fire, delayed or simultaneous, at unexpected distances from the source. When metal structural members or pipes have been heated, they should be checked at appropriate distances.

Silver is the best heat conductor of the ordinary metals and lead the poorest, only one-fourth as good as silver. Granite, limestone, ice, water, brick, glass, and plaster are of medium conductivity. Wood, asbestos paper, sawdust, paper, linen, silk, cotton, wool, and air are poor conductors. It should be noted that the transmission of heat cannot be completely stopped by any heat-insulating material.

Heat Transfer by Convection. The material on convection represents in large measure deductions based on personal observations by the author at approximately thirty-five hundred fires of various sizes and types over a period of nearly thirty years. In addition, the ideas expressed conform to the well-established fact that, when not acted upon by a fan or other impeller, air or any fluid flows from a region of higher to one of lower absolute total pressure without regard to atmospheric pressure. (Absolute pressure equals the atmospheric pressure plus gage pressure, if the latter is positive, or minus gage pressure, if it is vacuum pressure.)

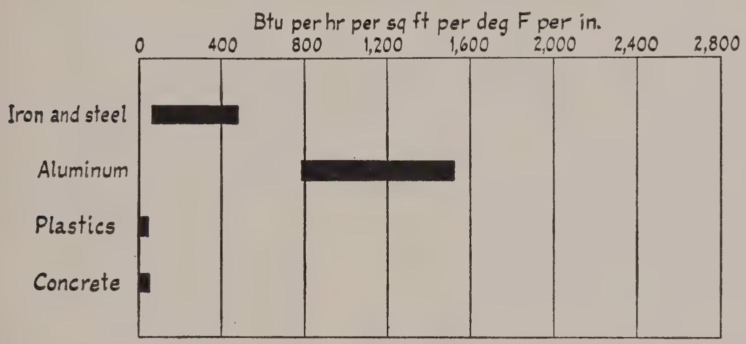

FIG. 1-4. Thermal conductivity range for various materials. (*From "The Contemporary Curtain Wall," by William Dudley Hunt, Jr., McGraw-Hill Book Company, Inc., New York,* 1958.)

Convection is the process in which heat is transferred by a circulating medium in the gas or liquid state. Thermal columns (pillars of heated air and gaseous products of combustion) in conflagrations are examples of convection by a circulating gas. The flow of molten metal is an example of convection by a circulating liquid. Gaseous products of combustion combine with air, whose density is reduced by the heat. Such mixtures are invariably lighter and more buoyant than air alone. Their usual tendency is to rise, although convection currents can be carried in other directions as well. The direction of the current is determined by pressure differences, which are influenced by elevation and temperature.

Atmospheric pressure at sea level is about 15 pounds per square inch (psi), 30 in. of mercury, 34 ft of water, or 408 in. of water. The last measurement is used in gages to indicate the difference between atmos-

pheric and duct pressures. Atmospheric pressure decreases 1 in. of water for each 69.2-ft increase in height above sea level. Thus, 69.2 ft above sea level atmospheric pressure is 407 in. of water, and 69.2 ft below sea level atmospheric pressure is 409 in.

Temperature affects the density (mass of a substance per unit volume) of the air. The density of standard air at 70°F and 29.92 in. of mercury is 0.075 pound per cubic foot (pcf). When the air is heated to 340°F, the density is 0.05 pcf. A 70-ft column of air and gases with a density of 0.05 pcf will exert a pressure of 0.05×70, or 3.5, pounds per square foot (psf) at the bottom inside a shaft (duct, incinerator, piped recess, or similar vertical channel), compared with a pressure of 0.075×70, or 5.2, psf on the outside. The difference is 1.7 psf, or 0.0118 (approximate) psi, which may seem insignificant until it is realized that a pressure of differential of 0.01 psi is sufficient to cause standard air to flow at a velocity of 2,100 ft per minute.

Fire officers want to know how uncontrolled convection currents act at fires and what can be done during fire operations to help rescue work, minimize the hazard to fire personnel, check extension, and efficiently extinguish the fire in the presence of convection currents. The following discussion considers convection in relation to tightness of the building structure, construction, fire location, burning material, weather, and mechanical ventilation.

To examine the convection paths in a structure with ordinary openings, let us assume that a fire originates on a lower floor of a five- or six-story building of non-fire-resistant construction. The heated gases usually given off at fires, being considerably lighter than the surrounding air, rise and leave behind a low-pressure area, which commonly induces a horizontal draft toward the fire below. Few buildings are so tightly sealed that air cannot infiltrate around doors and windows to sustain combustion, and few fires are so effectively shut off from an air supply that they exhaust the available oxygen. An occasional fire starting in a tightly closed closet may die out for lack of oxygen, but the very nature of fire helps create an oxygen supply. In the assumed conditions, the rising gases will very likely ignite, spread horizontally on the top floor, crack window panes, and appear through the broken windows. Although the structure is closed, it has vertical channels such as stairways and shafts that make extension possible. In some cases, heavy involvement of the cockloft precedes the show of fire at the top-floor windows. Such involvement could occur, for example, if the fire travels upward only through a pipe recess directly into the cockloft. The circulating heated gases (convection currents) under such conditions follow the route dictated by density and pressure differences. Ordinarily, therefore, assuming the required pressure difference, they will travel upward via the nearest and most accessible vertical channels (Fig. 1-5).

If the rise of convection currents in a shaft is checked by some obstruction, and if the stoppage is complete and sufficiently prolonged, a positive pressure will build up and will be greatest immediately beneath the stoppage. Unless the pressure is relieved by ventilation work or by the fire burning through the obstruction, heated gases and smoke will flow toward areas of lower pressure, generally resulting in horizontal extension of fire (mushrooming) or, in some instances, in limited downward spread through vertical channels in which pressures are lower. The positive pressure decreases at lower levels, and hence downward spread is limited. Model cases can be seen at fires involving a clogged incinerator, where smoke conditions are worst on the floor just below the obstruction and create less of a problem on lower floors.

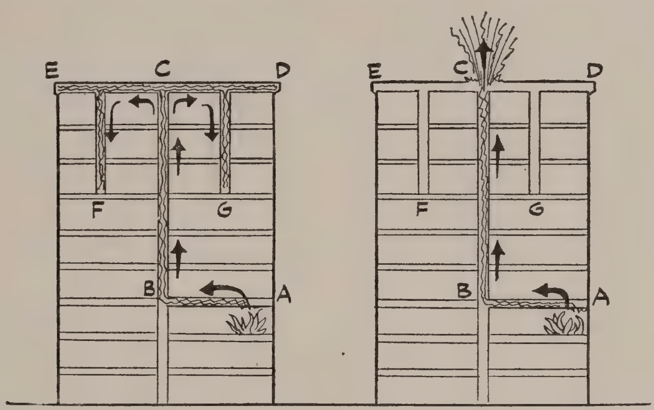

FIG. 1-5. Potential flow of convection currents within a structure.

Let us assume that a structure is closed so tightly that the oxygen available will not sustain combustion. What is the pattern of convection currents if a fire starts? A fire in such a building can burn until the oxygen is reduced below the 15 per cent required for active combustion. Then active burning will cease, despite the fact that many parts have been heated above their ignition temperatures. Heated gases will rise as previously described, through the most available vertical channels, and heat items at the upper levels. Although active burning ceases or is retarded, such a building can readily be turned into an inferno if a broken window or forced entry enables the oxygen supply to be replenished at or below the fire floor. When the oxygen supply is adequate, active burning will start on the upper levels also. Only oxygen is needed to ignite the heated gases and materials there.

The fire service must recognize the possibilities in such a situation. Sufficient hose lines should be stretched and made ready for prompt use before such structures are opened up. The most serious possible result should be considered and prepared for. Adequate roof (and rear or side,

if practical) ventilation should be effected before forcible entry is attempted at the street or fire level. If a sudden opening is made in the roof with an axe, heated gases pushing through may burst into flame when they meet a plentiful oxygen supply. Gas contents of the cockloft, however, will not necessarily ignite, as there may still be an oxygen deficiency within. Opening the roof allows the pent-up heated gases to escape and so reduces the possibility of a back draft when forcible entry is made at a lower level. Forcible entry will supply oxygen to the fire, but the additional heat created will be transferred by convection along the path of least resistance: upward and out through the roof opening. With this knowledge, the firefighter is better able to predict and control the direction in which the fire will travel.

Back draft, always a hazard at a fire, is essentially the ignition and rapid combustion of a mixture of flammable gas or dust and air. Sometimes called a *smoke explosion* or a *hot-air explosion,* it flashes or explodes back through openings in a fire area. The interval of time between the opening up of a structure and the occurrence of a back draft is influenced by (1) the type of gases in the fire building and their temperature, pressure, and content; (2) the volumetric areas involved and their location in the building; (3) the type, size, and location of the opening made by the fire department; and (4) the direction and velocity of the wind.

A gas rather commonly associated with back drafts is carbon monoxide, which has a wide range of flammability (12.5 to 74 per cent); an increase in temperature or pressure widens this range. The ignition temperature of carbon monoxide (1204°F) is easily reached at fires. Other gases, such as hydrogen, methane, and natural gas, combine a wide range of flammability with readily reached ignition temperature. A fire officer should be alert to the possibility of a back draft when a door is opened and the smoke seems to be drawing back toward the fire within. This appears to be caused by a reversal of flow induced by a mixture of the (outgoing) gases with the incoming air. A back-draft explosion is imminent in such cases (Fig. 1-6). It is important to be able to recognize the symptoms, but it is much more important to know how to prevent such an explosion. Proper ventilation, of course, is important (Chap. 11).

Convection paths in a modern fireproof or fire-resistive building are ordinarily horizontal. If the doors leading to fire stairs in such a building are closed, as they should be, there is little likelihood of fire spreading from one floor to another, except by way of air-conditioning ducts. In some cases, smoke and heated gases may enter elevator shafts and travel ten or fifteen floors, but it is unlikely that the shafts will be seriously involved in the fire. The situation is usually relieved by venting the shaft at the top, although these shafts should not be used to vent the fire floor.

A building with an air-conditioning system provides both vertical and horizontal pathways for fire. On the other hand, windowless buildings tend to restrict the spread of fire by convection into or from such buildings. Large undivided areas and unprotected vertical channels in

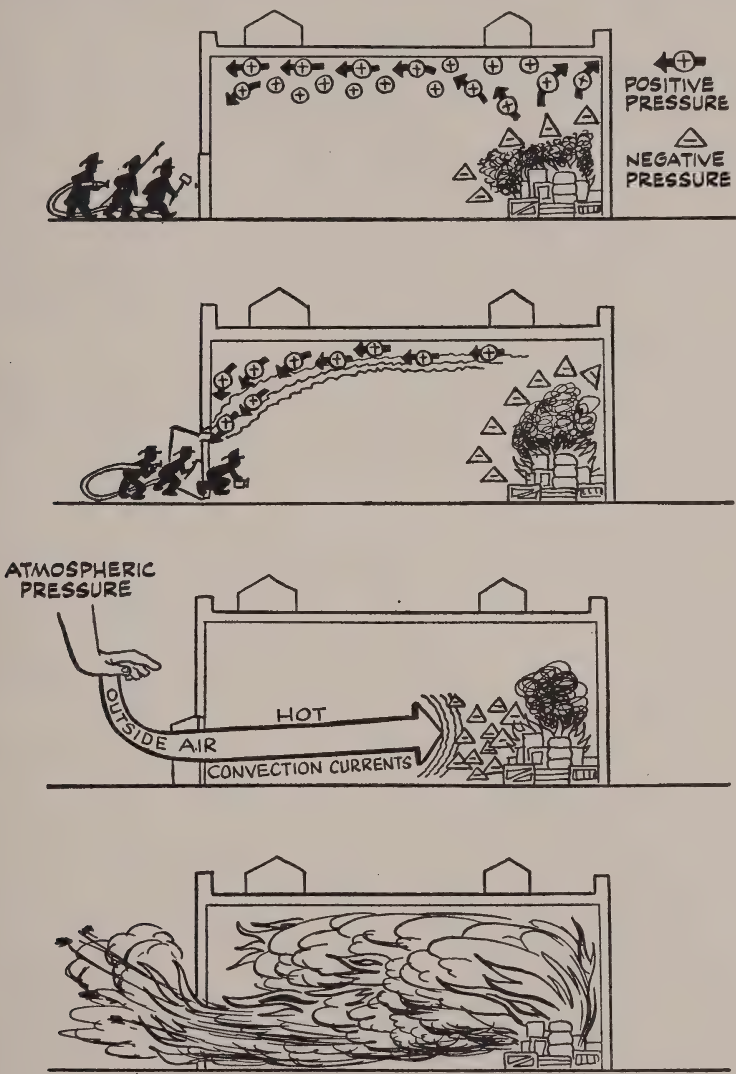

FIG. 1-6. Development of a condition conducive to a back draft.

a building favor extension of fire by convection, since the heated gases can travel unimpeded in any direction aided by the prevailing draft.

Wooden walls and partitions in frame dwellings fall easy prey to hot convection currents. In many dwellings, the roof has a considerable over-

hang at the eaves. Roof overhangs, as well as those of small fixed awnings and over shutter and door openings, tend to pocket heated air currents and materially further the spread of fire by convection currents.

The spread of fire by convection is also modified by the origin of the fire within the building. Fires in basements, cellars, and subcellars are usually slow-burning and smoky due to oxygen deficiency. They produce many unburned vapors from combustible materials and some carbon monoxide, frequently at temperature below 1000°F. The volume of gases produced in such fires is large, and the buoyancy of the gases is low. Consequently, the heat transfer by convection, vertically or horizontally, is retarded. If, on the other hand, the fire is located near drafty vertical channels, it could readily spread to the upper parts of the building. In any event, however, spread of the fire by convection would be retarded until the gases were sufficiently heated and buoyant for the required circulation.

Certain materials, such as oils, greases, fats, rubber, wax, tar, and some plastics, often produce large volumes of smoke that are largely unburned vapors. The heat of such smoke is low, as is its buoyancy. Therefore, regardless of where such fires are located, heat transfer by convection will be retarded.

If the burning material is susceptible to rapid combustion (such as sisal or loose excelsior) and sufficient oxygen is available, heat will be produced quickly; this, in turn, will increase the rate of combustion, since it is well known that the rate of chemical change involved in the burning of ordinary combustible material approximately doubles for every 18°F rise in temperature. Thus, in such fires, highly heated and buoyant gases will develop and circulate rapidly.

Convection is affected by weather in two ways: convection pathways may be modified, and fire temperatures may be modified.

In the initial stages of a fire, wind affects the rate of combustion. A small draft produces a slow fire, since not enough oxygen is being supplied. On the other hand, a strong draft may cool the burning material enough to retard the generation of combustible gases. In addition, when a large volume of air mixes with vapors from materials such as wood, the resulting mixture, being too lean, may not burn.

When a fire is well-established, strong winds may increase the rate of combustion and the heat output as well as affect the path of convection currents emerging from the fire building. The hazard of fire extending to nearby buildings is intensified if the wind is blowing toward them. Conceivably, the wind would affect convection paths inside the fire building if exterior openings favored such a development.

Fires of conflagration proportions are characterized by *pillaring* of heated air and products of combustion, which may rise several hundred

feet or more in the air, depending on the wind velocity. Such a pillar can carry sparks and burning brands of considerable size to incredible distances when it is driven by strong winds, which must be 30 or more mph in order to promote a conflagration. Strong winds influence the direction in which a conflagration will move; the higher the wind velocity, the more the pillar of heated air slants in the direction of the winds.

Humidity and inversion also affect convection. *Inversion* refers to stratification of layers of air of different temperature. Occasionally, there is a radical temperature difference between two adjacent layers or strata. The line between two strata is referred to as the *floor* of the upper stratum and the *ceiling* of the lower stratum, and it can form a barrier to convection currents until temperatures alter sufficiently to break down the ceiling. This phenomenon is called a *lapse*.

High humidity combined with inversion when a fire begins will retard the formation of a draft or pillar of heated air. High humidity generally prevails during the rainy seasons. In addition, rain droplets cool convection currents and may also extinguish flying sparks and embers. Rain also affects convection in that wet structures take longer to ignite when exposed to heated air. The effects of snow are in many ways similar to those of rain.

Mechanical ventilation, consisting of electrically driven fans and blowers, has a strong effect on convection currents developed by fires in or near duct systems, subway or railroad tunnels, and vehicular tunnels.

When heat from a fire is traveling by means of convection through a duct system connected with a large cooking range or an air-conditioning system, the operating fans accelerate the rate of combustion and extension of fire. Fans should be shut down promptly in such cases (unless essential for ventilation and rescue purposes) to decelerate the rate of combustion and fire spread as well as to locate and then isolate the fire by the use of dampers or other means. However, fog injected into the lower sections of a ventilation system will vaporize if there is sufficient heat (above 212°F), and it will expand and circulate through the ducts with greater effectiveness while the fans are operating. Inlets to an air-conditioning system located in exterior walls should be closed if there is any possibility of smoke or heated gases entering the system. The importance of knowing the location of shutoffs in such systems is obvious. For further discussion of air-conditioning systems and fire operations, see Chap. 6.

In some cities, subway fires pose a very serious problem. Here again, powerful fans influence the direction of convection currents. Almost invariably, fires in subways can be extinguished by one hose stream, or even by hand extinguishers, but the potential life hazard involved gives

them a far greater importance than the extent of the fire ordinarily warrants. It is extremely important at such fires to know in what direction the fans are blowing. If the direction is unfavorable, the fans should be shut down, or reversed, if that is possible and desirable. Effective communication and preplanned agreements between fire officers and transit authorities are necessary so that fire-service requests can be carried out promptly by the transit authorities, who know whether a request should be complied with at once or only after immediately endangered trains have been given sufficient time to clear or back out of the hazardous area (see Chap. 14).

Some vehicular tunnels, such as the Holland Tunnel, have extensive ventilating equipment primarily to control the concentration of carbon monoxide from motor exhaust. When a fire occurs, an emergency procedure is utilized to confine fire, smoke, and convection currents to the ventilation section in which the fire originates. By shutting off the blower fans (with exhaust units operating) in the fire section and the exhaust fans (with blower units operating) in adjacent sections, a longitudinal flow of air is directed toward the fire area from each side, thus minimizing the spread of smoke and heat to other sections. When such emergency procedures are utilized, exhaust fans may be subjected to severe heat; wherever possible, the fans should be cooled by water from hose lines. Intense heat can be expected in the fan room, and precautions (stretching and using fog lines, etc.) should be taken accordingly to protect personnel and equipment.

Convection may abet the spread of fire, but it may also assist the fire department during the ventilation process as well as in the actual extinguishment of the fire. During ventilation, heated gases and smoke escape by convection, making it possible for firemen to conduct interior operations more effectively; water supplied to the fire absorbs heat and thereby becomes a medium of helpful convection. Water in the form of fog is the most helpful, but it is possible that very hot convection currents will be created if the fog vaporizes to steam. Operations should be conducted so that the heat moves away from, and not toward, advancing fire personnel. Controlled ventilation (opening up the structure or using mechanical means to control the direction of convection currents) is an urgent matter in such situations.

Convection and Smoke. Convection can occur without smoke. For example, heat is transferred in an air-conditioning system by convection without smoke. At fires, however, smoke is most often present. Smoke has been defined as the volatilized products of incomplete combustion of an organic compound, such as coal or wood, charged with fine particles of carbon or soot. Under the influence of heat at fires, many chemical elements combine and others are liberated; the resulting product is a smoke

or gas of varying mixture. When many materials burn, free carbon is given off in the form of soot, or as minute particles that produce the blackness of smoke. Smoke behaves in many ways like a gas; both are subject to some of the same natural laws.

Visual observations of smoke and convection currents may enable the commanding fire officer to deduce the following: (1) the kind of material burning; for example, white, yellow, or black smoke could indicate the involvement of phosphorus, gunpowder, or petroleum and petroleum products; (2) suspicion of arson; for example, if fast-burning materials strange to the occupancy are present; (3) the location of the fire; (4) the extent of the fire, which at times can be gaged by the area of the thermal column rising above the fire; (5) the temperatures developing—rapidly rising convection currents may indicate that high temperatures are developing and are quickly reducing the density of the air causing such an ascent; (6) whether the pressure within a structure is positive, as revealed by jets of smoke issuing from loose-fitting doors or windows, or negative, as indicated by the withdrawal of smoke toward the interior when a door or window is opened; (7) the severity of the exposure hazard; (8) whether ventilation will be difficult; (9) when hose streams are hitting the fire, whitening the smoke.

Flame

Flame is now considered to be a subtle process by which molecules are rearranged and yield radiant energy. New and important information relative to flame and heat may be forthcoming because of increased scientific effort and interest.

Progress is very slow, however, because flames are extremely complicated and are only partially understood. The high temperatures and short time periods involved in combustion of a given molecule of fuel make direct experimental studies very difficult.

When wood is heated sufficiently under fire conditions, it first undergoes thermal decomposition (destructive distillation); various combustible gases or vapors are evolved, which burn as the familiar flames. After these volatile decomposition products are driven off, the combustible residue is essentially carbon (charcoal), which, on further heating, reacts at the surface with the oxygen of the air, producing considerable heat (glowing) but usually very little flame. Usually, during the first stages of a fire (evolution and burning of gaseous decomposition products) flames travel rapidly over the surface of wood or similar combustible solid materials, and glowing flameless combustion of the charcoal embers follows.

The luminous flames commonly associated with fires are sometimes

described as *diffusion flames,* since the combustion occurs in the zone where the unburned vapors or decomposition products intermix with the surrounding air as they evolve. Because the rate of mixing, among other factors, influences the characteristics of diffusion flames, they differ in many respects from flames that propagate in gases, vapors, or dusts premixed with air before ignition.

Combustion

Combustion can be defined as a heat-producing process that may take place at almost any rate and at almost any temperature; it may be as slow and mild as the rusting of iron (not all textbooks agree on this point) or as violent as the explosion of hydrogen with oxygen, which involves temperatures of 3000°C. Combustion does not necessarily involve oxygen, but the fire service is mainly concerned with combustion that does require oxygen. Some metals, such as magnesium, may burn in nitrogen, and certain substances, such as hydrazine (N_2H_4), hydrogen peroxide (H_2O_2), and ozone (O_3), can burn in the absence of any medium except themselves; that is, at sufficiently high temperatures they decompose and give off heat without combining with another substance. Ozone, in burning, gives only a single product: two molecules of ozone yield three molecules of oxygen plus heat. Other examples of combustion without oxygen are the hydrogen-fluorine torch and the burning of hydrogen in an atmosphere of chlorine.

When combustible organic material, such as wood or flammable liquids, burns freely in an atmosphere containing plenty of oxygen, the volatile products of combustion are mainly carbon dioxide and water vapor. In an atmosphere that is deficient in oxygen, appreciable quantities of carbon monoxide, smoke, and other products of incomplete combustion may also be present.

The chemical composition of common woods (dry basis) is essentially as shown in Table 1-1.

Table 1-1

	Per cent by weight
Carbon	48.0–51.0
Hydrogen	5.9–6.3
Oxygen	39.0–45.0
Nitrogen	0.1–1.0
Ash	0.2–3.4

Many common flammable liquids consist of carbon and hydrogen chemically combined in various proportions (hydrocarbons) or of carbon, hydrogen, and oxygen in combination (alcohols, aldehydes, ketones, organic acids, and ethers).

During combustion, hydrogen and carbon react with oxygen in the air to produce carbon dioxide and water vapor. The chemically combined oxygen in these materials is not available for the usual combustion reactions, but it is available in a substance such as cellulose nitrate, which is capable of undergoing exothermic decomposition. (*Exothermic reactions* are accompanied by the liberation of heat, as opposed to *endothermic reactions,* which are accompanied by the absorption of heat.)

What is fire? It is any combustion intense enough to emit heat and light. It may be quietly burning flame or a climactic explosion. Fire grows and sustains itself in the reacting medium by the heat it produces: heat raises the temperature, and the temperature, in turn, increases the reaction rate until heat is produced as fast or faster than it is lost to the surroundings. However, heat is not always the sole, nor even the principal, agent that initiates flames and explosions. Fire may be started by a chemical process known as *branching of reactions chains.* The study of branched reactions is obviously of interest and of use to the fire service, but it is only briefly mentioned here. Branched reactions are similar to the nuclear chain reaction of the atomic bomb.

The Combustion Wave. A combustion wave is a propagating zone of intense burning. In gas-phase combustion, a spark starts the chemical reaction in a small zone of the fuel mixture; as this flames up, heat flows into the adjoining layer of unburned gas, and so on, like a wave. The combustion wave is divided into three zones: (1) the preheat zone, (2) the reaction zone, and (3) the completed-reaction zone (see Fig. 1-7).

In the preheat zone, the temperature of the fuel and air is raised by the excess enthalpy (excess heat content) of combustion. The spark starts the chemical reaction, and the temperature rises.

In the reaction zone, the mixture is further heated by the combustion of the fuel. When a hot enough part of the wave reaches it, the gas breaks into rapid chemical reaction, or flame. This burning generates heat, at a rate that first rises and then declines as the fuel is used up.

In completed-reaction zone, the fuel is completely burned. The heat still being generated passes forward to the advancing wave front as much heat as it absorbed before it began to liberate heat. In this way a combustion wave continuously "borrows" and "repays" heat from its excess enthalpy.

Combustion-wave thickness and temperature gradient vary greatly, depending on the fuel: in a mixture of hydrogen and fluorine, the temperature rises about 4500°C in the space of about one-thousandth of an inch.

The velocity at which the wave propagates is called the *burning velocity.* Burning velocities range from a few inches per second for weak

hydrocarbon-air mixtures to several hundred times this value for mixtures such as hydrogen and fluorine. The difference in burning velocities is important to firefighters because in simple combustion, involving gas-phase combustion alone, extinguishment can be readily effected by interrupting flame propagation in a zone for as long a time as it normally takes a flame to propagate through the zone.

If an explosive mixture flows continuously from an orifice, a combustion wave can, under suitable conditions, propagate against the stream at a rate that matches the flow velocity of the stream. This is seen in the

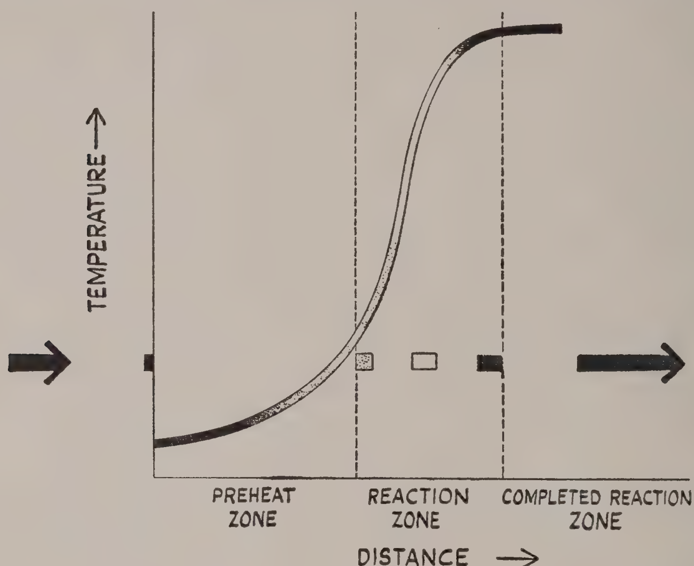

FIG. 1-7. The combustion wave is divided into three zones. In the preheat zone the temperature of the fuel and air is raised by the excess enthalpy of combustion. In the reaction zone the mixture is further heated by the combustion of the fuel. In the completed-reaction zone the fuel is completely burned. The small rectangles suggest changes in volume with burning. (*Scientific American.*)

stationary flame of the kitchen gas range. In the kitchen range, a jet of fuel gas, after entraining air, flows under pressure from numerous orifices in the burner head. The flame is stabilized by the controlled flow distribution and the quenching effects.

The combustion wave anchors itself at an equilibrium position whose distance from the burner rim depends on the rate of gas flow. When the velocity of the gas flow is reduced to less than the burning velocity, the flame theoretically flashes back into the piping. In large oil and gas installations, tanks are provided with *flame arresters* to guard against such a possibility. When the velocity of gas flow exceeds the burning velocity everywhere in the stream, the flame blows off. It is well known

that gas- and oil-well fires, again involving gas-phase combustion alone (assuming no exterior extension), can be extinguished by the explosion of TNT as near to the center of the fire as possible. The explosion interrupts flame propagation, and it seems reasonable to speculate that the shock and concomitant wind increase the velocity of the flowing gas over the burning velocity of the gas and the flame blows off.

Combustion waves lose heat to solid bodies with which they come in contact. A solid, therefore, quenches burning in a gas for some distance from it. If the diameter of a duct is made small enough, an explosive mixture cannot burn in it. The critical quenching diameter depends upon the composition of the fuel mixture, the pressure of the mixture, the temperature, and the shape of the duct. A mixture of hydrocarbons and air at very low pressure will not burn in a duct as much as several inches in diameter, but a mixture of oxygen with hydrogen or acetylene can propagate a flame in a fine tube as small as one-thousandth of an inch in bore.

The minimum spark energy required for ignition depends upon the composition of the explosive mixture, the pressure, and the temperature. Certain weak mixtures may require as much as a calorie, whereas hydrogen and oxygen in proper ratios can be touched off by less than one-millionth of a calorie—a spark far less energetic than the static electricity a human being generates by walking on a carpet on a dry day. It is possible for a low-energy spark to pass through an explosive mixture without igniting it, even when the temperature in the path of the spark is of the order of several thousand degrees. This can occur if the potential combustion wave is not given a sufficient initial boost of heat by the ignition source; as a result, the temperature drops so much that the wave dies.

Fire-service Research

The fire service plays a very minor part in research on problems and phenomena connected with fires and fire prevention, despite the huge fire losses in the United States. Fires annually destroy about 11,500 lives, and total fire costs are 5 billion dollars per year. The estimated annual cost of *fundamental* and *applied* research, development, and testing in the United States is about 20 million dollars—less than 0.4 per cent of the total monetary loss. Whereas in industry approximately 3 per cent of expenditures is spent for reesearch and development, in the nation at large only approximately 0.02 per cent of the estimated annual fire costs goes for *fundamental* fire research. As a result, new problems are not properly anticipated, solutions are derived belatedly or not at all, and fire losses continue at staggeringly high levels.

Very few fire departments have the finances or facilities to conduct research on a worthwhile scale, and the fire service is mostly dependent for research information on other agencies. A selective list of research facilities and projects of interest to firefighters is given below.

1. American Gas Association Laboratories, with approximately 170 technical engineers and laboratory facilities for testing gas appliances with at least six types of gas, checks the design and installation of gas-using appliances for possible fire and other hazards. It also publishes a directory of approved gas appliances and listed accessories. In addition, sets of standards are prepared and kept revised.

2. The office of the California State Fire Marshall conducts research and tests on flame-retardant treatment processes; the flammability of textiles; the classification and labeling of fireworks; and the characteristics of flammable liquids, chemicals, and building materials.

3. At Columbia University, the chemical engineering department has conducted research for at least ten years on the combustibility and flammability of textiles and clothing, a project sponsored by the Quartermaster Corps, United States Army.

4. The technical staff of the Francis Earle Laboratories, Peekskill, New York, has made a study of extinguishing agents that can be used effectively on magnesium fires and of the use of mechanical foam in extinguishing liquid-fuel fires.

5. The Factory Insurance Association, Hartford, Connecticut, maintains a technical staff with facilities for conducting research on explosion pressure of dusts and explosive characteristics of hazardous vapor-air and gas-air mixtures. The staff also determines flash points and ignition temperatures. They publish recommended practices relative to industrial fire hazards and protection, and they give training courses in which members of public fire departments are sometimes invited to participate.

6. The Grinnel Research and Development Division, Providence, Rhode Island (sponsored by the Grinnel Company, designers and installers of special-hazard fire-protection systems), with its technical staff, equipment, and facilities, studies newly developed hazardous materials and processes and determines proper methods and materials for fire detection and control; tests (outdoor) use of water-spray systems for control of fires in transformers or in open tanks of flammable liquids or for protection of exposed tanks, etc.; and tests fire-extinguishing agents such as foam, foam-water spray, carbon dioxide gas, and dry chemicals.

7. The University of Maryland Fire Service Extension, part of the college of engineering, with its own staff members, has at its disposal 25,000 sq ft of modern building floor space, 20 acres of yard space, and equipment for a program of fire-service training that includes fire prevention, protection, and suppression. Practically every commercial fog

or spray nozzle sold in the United States has been studied. Experiments have been made to control by means of fog nozzles the direction in which fire drafts move. The movements of air during fires, as affected by fog nozzles, were also studied.

8. Oklahoma A & M College, Stillwater, Oklahoma, maintains a teaching staff, with ample laboratory and classroom facilities in the school of technical training. A two-year course has been laid out, during which students are instructed in industrial and municipal fire protection. Related research is conducted.

9. At the Southwest Research Institute, San Antonio, Texas, there is a fire technology section within the engineering mechanics department. This induces close cooperation with other departments, thereby providing a wide range of facilities and skills available for fire research.

10. The Underwriters Laboratories, Inc., with four main stations in New York City, Chicago, Santa Clara, California, and Northbrook, Illinois, perform fundamental research and, by contract, perform standardization and testing functions for individual manufacturers and other organizations. They also determine fire-resistive ratings of structural parts; test wire installations, fire hose, water-supply equipment, etc.; and approve and label devices for safety, rejecting others.

11. The Division of Forest Fire Research, U.S. Department of Agriculture, plans and administers a program for fire research at experimental stations, research centers, and experiment areas.

12. The Intermountain Forest and Range Experiment Station, Ogden, Utah, conducted Project Skyfire, a project of research in upper air and cloud conditions aimed at elimination of lightning fires and improved forecasting.

13. California Forest and Range Experiment Station No. 347, Berkeley, California, in conjunction with various agencies of the U.S. Forest Service and four other California State agencies, carried out Operation Firestop, probably one of the most extensive projects of its kind. It was designed to search for solutions to difficult fire-control situations: those causing heavy damage or loss of life and those which are difficult to control with existing equipment and techniques. The project involved a study of the use of fire retardants for forest fires, techniques for accelerating backfiring, and methods of applying water from the air.

The working group averaged about forty men. The 200 test fires required the construction of 25 miles of firebreaks, 10 miles of roads and jeep trails, and three heliports and the installation of 22 weather stations, 18 wind towers, and 14 continuous-recording stations.

During Operation Firestop, over a three-month period, fuel and climate measurements were made on all test fires. Eleven fires were set in order to develop means of measuring heat-transfer characteristics. Wind studies

and temperature and humidity soundings were made twice a day during fires at various levels.

14. The Fire Protection Section, National Bureau of Standards, U.S. Department of Commerce, studies causes of fires, including self-ignition phenomena, methods of fire detection, and evaluation of fire-detection equipment. It does research on mechanisms of fire extinguishment and publishes a monthly *Technical News Bulletin*.

15. The U.S. Navy Material Laboratory at the Brooklyn Navy Yard, New York City, carries out experiments with mechanical-foam liquids, foam-generating equipment, water-sprinkler systems, vaporizing liquids, and dry-chemical-foam powders and studies the extinguishment of alcohol, gasoline, rocket-fuel, and metal fires. Reports, however, are prepared for the armed forces only.

16. The Factory Mutual Laboratories, Norwood, Massachusetts, have extensive research facilities, including a large industrial-type building (60 by 120 ft) for fire tests; a concrete explosion tunnel (4,200 cu ft), for simulating large-scale industrial-type explosions; a gage developed to measure explosion pressure by the damage done to a brick wall, which enables various venting means to be investigated; a mortar tower (30 ft high), which permits varying the velocity of impact of a falling object and measuring this velocity before the impact; a furnace (100 ft long, 20 ft wide, and 10 ft high) useful for large-scale tests, which is offered to manufacturers of materials used in roof-deck assemblies; and a construction-materials calorimeter, in the form of a furnace, which determines, for various exposure conditions, the heat contribution within a building from any combustible construction material. The importance of this apparatus lies in the fact that heat contribution can be determined in absolute terms, usually expressed in British thermal units per square foot per minute.

With these facilities the Factory Mutual Laboratories test samples of materials (flammable liquids, dusts, textile fibers, etc.) submitted by industrial plants to determine fire and explosion hazards. The tests determine flash and fire points, susceptibility to spontaneous ignition, etc. Fire-protection devices and devices that might constitute a fire or explosion hazard are examined and tested, and results are published annually. In addition, original research to develop improved methods of loss prevention is conducted.

The foregoing list is brief and incomplete. In addition to the work of other government agencies, substantial research contributions are being made by large private organizations, such as Firestone Tire and Rubber, Walter Kidde, Carbide and Carbon Chemicals, and Ansul Chemical. Such research is intended to benefit the companies directly, but it indirectly benefits the fire service and the public.

This research, however satisfactory to the persons conducting it, is inadequate to the needs of the fire service. Particular problems of the fire service do not receive proper consideration because the service has only a small part in selecting research objectives. The fine work being done by Forest Service research units, the Fire Underwriters' Laboratory, the National Fire Protection Association, and others only demonstrates that the total fire-research effort is falling far short of what is needed to keep abreast of modern technology and scientific development.

Practically no research has been done on control of fire storms and conflagrations. Since existing techniques and tools are inadequate, an aggressive research program is the only answer to the problem. If research is to provide practical answers for the fire service, it must be in new fields and on a much greater scale.

Perhaps some needed answers will be provided by the Committee on Fire Research and the Fire Research Conference of the National Academy of Sciences, Washington, D.C. This committee and conference were established in 1955 at the request of the Federal Civil Defense Administration, and they publish *Fire Research Abstracts and Reviews,* which contains abstracts of papers published in scientific journals, progress reports on sponsored research, patents, and research reports from technical laboratories. Currently, these agencies have a commanding position in national and international research. At intervals, they publish reviews on selected subjects of significance in fire research, centered on the quantitative understanding of fire and its spread. They have sponsored symposiums on fire research on both a national and an international basis. In addition, they compile information about current research in many other countries, including the Soviet Union, as well as in the United States.

In order that firefighters may gain some idea of the nature and extent of fire research being done in other countries, a representative sample is listed here.

In Great Britain, the Joint Fire Research Organization, Boreham Wood, England, is studying ignition phenomena, models and fire research, and protective clothing against flames and heat; Imperial Chemical Industries, Stevenston, Scotland, is studying ignition by radiation; and the Fire Research Station, Elstre, England, is studying modeling problems associated with fire research. At the Atomic Weapons Research Establishment, Aldermaston, Berks, England, radiation fronts are being studied. In addition, research on a variety of subjects is conducted by the universities, particularly those of Cambridge, Leeds, Manchester, and Sheffield.

In the Soviet Union, research is being done at a variety of institutes: the Institute of Energetics, Academy of Sciences; the Institute of Organic

Chemistry, Moscow; the I. I. Polzunov Boiler and Turbine Institute, Moscow; the All-Union Institute of Natural Gas, Moscow; the Petroleum Institute, Academy of Sciences; the Central Science Institute for Research on Prevention of Fire in the U.S.S.R.; the Academy of Building and Architecture, Moscow. The subjects of research include chemical means of fire extinction, thermal decomposition of various substances, heat-transfer calculation, flame propagation, direction of fire spread, and fire resistance of construction materials.

In Japan, the Building Research Institute, Ministry of Construction, assigns one of its five sections to the functional study of fire protection. This section carries on fundamental studies in laboratories as well as fire tests of building materials. The Fire Research Institute, a laboratory of the National Fire Defense Board, conducts fundamental and practical research to improve techniques or equipment for fire protection, to grade cities on the basis of fire prevention and protection there, and to establish tests for approval of all kinds of fire-protection equipment and devices. The Fire Research Group of Japan, T. Kinbara, chairman, represents wide areas of fire research. The Fire Prevention Society of Japan has approximately eight hundred members, representing colleges, meteorological observatories, industrial and insurance companies, and city fire departments.

In Germany, research facilities include the Research Division for the Technique of Extinguishing Fires, Karlsruhe Polytechnical Institute, which is studying plastics in fires, extinguishing effects of halogenated hydrocarbons, most favorable size of drops for extinguishing fires with atomized water, and characteristics of fires in storage tanks; and the Bundesanstalt für Materialprüfung, Berlin-Dahlem, which is studying dust flames, ignition limits of wood dust, and flammability and combustibility of organic foam materials.

In France, the Sorbonne, the University of Paris, and the National Hydraulics Laboratory, at Chatou, conduct research on such subjects as extinguishment by detonating waves, suppression of explosion waves, and convection currents in large fires.

In Australia, the Bureau of Meteorology, at Canberra, is studying the association between the occurrence of major fires and a synthetic soil moisture index, and the Commonwealth Scientific and Industrial Research Organization, at Melbourne, is conducting research on the thermal decomposition of cellulose.

In Canada, in addition to the work of the National Fire Research Laboratory, Laval University Forest Research Foundation, Quebec, is studying flammability and heat content of the organic material of certain types of forests; the Royal Military College of Canada, Kingston, Ontario, is doing research on the formation of carbon from polyvinylidene, and

the Pulp and Paper Research Institute, Montreal, is studying the control of lightning-caused fires.

In Belgium, some important work is being done at the University of Louvain on chain branching and flame propagation, the extraction of ions from a flame, and the kinetics of flame inhibition.

In the United States, agencies conducting research, other than those already listed, include the Textile Research Institute, Princeton, New Jersey; Syracuse University Research Institute, Syracuse, New York; the U.S. Naval Research Laboratory, Washington, D.C.; National Advisory Committee for Aeronautics, Cleveland, Ohio; Stanford Research Institute, Menlo Park, California; Massachusetts Institute of Technology, Cambridge, Massachusetts; Bell Telephone Laboratories, Inc., Murray Hill, New Jersey; Argonne National Laboratory, Lemont, Illinois; Atlantic Research Corp., Alexandria, Virginia; Wright Air Development Center, Wright-Patterson Air Force Base, Ohio; and Applied Physics Laboratory, The Johns Hopkins University, Silver Springs, Maryland. Research subjects include various aspects of ignition, fire resistance, and fire extinction.

Conclusion. Two important factors differentiate research from application. Research personnel have in general very different training from that of persons engaged in the day-to-day application of the knowledge gained from research. A fireman and a physicist, for example, may see the same fire in quite different terms. Also, the data on which a research program is based are often less clear-cut and less subject to a practicable interpretation than are the concrete facts of an actual fire situation.

In every research program, however, some measure of control is needed. Especially in applied-research programs, in which a specific result is desired, some way must be found to control and ensure progress. Research, however, especially basic research, is an activity that demands the utmost possible freedom for those who work at it. These two conflicting needs—control and freedom—must be accommodated by cooperation and understanding between the research scientists and technicians and those who are anxious to apply the results of their work.

In the United States today there are two overall programs of research: applied research, which keeps fire-control activities abreast of scientific development, and basic research, which yields the fundamental data on which the applied research of five to ten years in the future will be based. This situation is inadequate to the nation's needs today, not because it is wrong in concept, but because in the critical times of the mid-twentieth century, we cannot afford a five- to ten-year lag in application.

In the author's opinion, the degree to which forest firefighting personnel participate in research is commendable, and commensurately

favorable results have been achieved. It may well be that such success is due in great part to a more effective blending of basic and applied research. Similar measures affecting community and city firefighting personnel are therefore strongly recommended. To this end the assistance of the Committee on Fire Research and the Fire Research Conference should be sought, for their stated aim is "to stimulate and advise on research directed toward the development of new knowledge and new techniques that may aid in preventing or controlling wartime or peacetime fires." If there is to be the desired blending, however, the fire-service personnel concerned should be given the opportunity to suggest and participate.

2

Extinguishing Fires

Before we consider methods of extinguishing fires and different types of fire extinguishers available, let us briefly examine the classification of fires into groups.

Class A fires are those occurring in ordinary combustible material, such as wood, paper, and cloth. The most commonly used extinguishing agent is water or a solution containing a large percentage of water.

Class B fires are those occurring in flammable petroleum products or other flammable liquids or greases. The blanketing-smothering effect of oxygen-excluding media is the most commonly used extinguishing method. In some cases, however, the use of dry-chemical extinguishing agents or the air-agitation method of extinguishment may be advisable (Chaps. 4 and 14).

Class C fires involve electrical equipment. In extinguishing such a fire, it is important to use an extinguishing agent that does not conduct electricity. After the equipment is deenergized, extinguishers suitable for Class A and B fires may be appropriate (Chap. 4).

Class D fires are those occurring in combustible metals (Chaps. 3 and 7).

Fire-extinguishing Methods

The existence of fire requires adequate flame temperatures fuel, and air plus a newly discovered factor: chemical chain reaction in the flame itself. Fire-extinguishing methods are based on eliminating one of

the required factors. Interrupting the flame chain reaction is a method that has great possibilities, and in the future, fires may be dealt with by means of certain ranges of frequency vibrations, by means of electrical energy, or by the use of detonation shock waves. Until then, however, the fire service will use existing methods of (1) cooling, (2) smothering, (3) starving the fire and, (4) blowing off the flame.

Cooling. Fires can be extinguished by cooling only by removing heat faster than it is generated. For maximum effect, water in fog form should be applied at the base of the flame so as to cool the actual burning surface.

Efforts are being made to establish acceptable standards of gallons of water applied to fires with known fire loads, a very worthwhile subject for research. The *fire load* is equal to the pounds of combustible material present times the average caloric value of the material per pound divided by the floor area in square feet. Theoretically, the total potential heat output can be calculated in some cases, but there are many and serious practical difficulties in establishing standards.

In the first place, not all the heat need be absorbed by the water for cooling to take place, for much of the heat is carried away by radiation and convection. In the second place, the fire may be in an unpredictable stage and state of combustion (incipient, advanced, or complete) by the time the fire service arrives, and the amount of water required therefore varies. Thirdly, many factors affect the efficiency of extinguishing operations: the presence of a life hazard could alter the quantity of water needed; inadequate water supply, street congestion, blocked hydrants, simultaneous fires, unfavorable time and weather conditions, inaccessible location of the fire, and unusual difficulty in ventilating can all influence the situation. Finally, sometimes, because of the need to prevent fire extension to other structures, all streams initially available cannot be directed on the main body of the fire.

Smothering. Carbon dioxide, steam, carbon tetrachloride, chemical or mechanical foam, asbestos blankets, sand, graphite, covers for large cooking kettles in oil and varnish occupancies, etc., can smother fires. Carbon dioxide is effective mainly because it reduces the oxygen content of the air to a point at which combustion is not sustained. A reduction of oxygen content of the air from the normal 21 per cent to 15 per cent will extinguish most fires in spaces in which there are no materials that produce glowing embers or smoldering fire. The amount of oxygen needed to sustain combustion varies with different materials, and reduction of oxygen to considerably less than 15 per cent is necessary in some cases. Where glowing embers or smoldering fires are a factor, or if the fire involves highly heated metal containers, it is necessary to reduce the

oxygen content of the air to 6 per cent or less and to maintain the reduction for more than the normal brief period. Where the fire is deep-seated and the material involved acts as a thermal insulator, it may be necessary to maintain a low oxygen dilution for hours.

Under certain conditions of control and application, a cooling effect is also achieved. Carbon dioxide snow has a latent heat of 246.4 Btu per pound, but since only part of the liquid carbon dioxide is converted to snow, the total cooling effect of the gas and the snow is considerably less. If the liquid is stored at 80°F, about 24 per cent is converted to snow upon discharge, with a total cooling effect of about 120 Btu per pound; if it is stored at 0°F, about 45 per cent is converted to snow, with a cooling effect of about 170 Btu per pound. The cooling effect is small when compared with that created by water, with its theoretical cooling effect of about 1180 Btu per pound, assuming that all the water is evaporated into steam.

Steam extinguishes fire by excluding air or reducing the oxygen content, as do carbon dioxide and other inert gases. For successful use, a sufficient quantity of steam must be available, and its limitations must be recognized. Steam is used to combat marine fires and fires in locations such as lumber dry kilns and flammable or combustible liquid vats, where high temperatures are usual and the introduction of cold water might cause severe container damage. Such damage is unlikely if fog is used, since the fog would vaporize. Pressure at the discharge orifice of each steam jet is generally not less than 15 psi. The amount of steam required will vary with the nature and size of the occupancy being protected.

The practice is to limit the use of steam to small enclosures. Tests at large-scale gasoline fires (involving as much as 55,000 barrels) proved unsatisfactory and impracticable, due in part to the time required to develop a safe concentration (40 per cent) in the vapor space above the gasoline, even though large boilers were used to supply the steam. Steam is completely ineffective with fires involving ammonium nitrate and similar oxidizing materials, and although used on many vessels, it is not recommended for those engaged exclusively in the carriage of coal or grain in bulk.

Steam hand lines are sometimes used to combat fires in rubber-spreading and cloth-coating processes where a flammable coating is used.

Carbon tetrachloride can smother a fire because the fumes it gives off do not support combustion and are heavier than air. Dry chemical powder can also smother fires. These agents are discussed further in Chap. 3.

Wet burlap bags, asbestos blankets, sand, graphite, and similar items

deplete the oxygen supply to a fire by mechanical means. In some industries, automatic covers close when a fusible link is fused by heat and thus smother the fire.

Foam is used primarily to extinguish flammable-liquid fires. It blankets the liquid surface, insulating it from the air and cooling it. Hence, the supply of oxygen to the flaming surface is cut off. To be effective, the foam bubbles must be relatively heat-resistant and long-lasting, and the foam must be delivered to the fire faster than it breaks down under fire exposure. Foam blanketing has an outstanding advantage: it can prevent reignition. Chemical and mechanical foams are compared in Chap. 3.

Starving. In starving a fire, the supply of burnable material is reduced or eliminated, thereby slowing up or stopping combustion. For example, in gas fires, when the gas supply is shut off by a valve or other means, the fire starves. In oil-tank fires, the contents of the fire tank or an exposed tank can be drained off in a prearranged manner to remote storage tanks; again the fire starves. Grass and brush fires can be starved by the backfire technique. The fire will die when it reaches the burned area because there is no fuel. Class A fires can be starved by moving combustible material to a safe area. This is frequently done when a ladder company checks an exposed building: windows may be closed, and stock endangered by heat radiating from the fire may be moved to a safer area. Moving trucks or other vehicles from a garage or ships from a pier can also reduce the amount of combustible material exposed to a fire.

Blowing Off the Flame. The flame is blown off when the flow velocity of a gas is made to exceed its burning velocity by the use of control devices in gas stoves, oxyacetylene tanks, and the like (see Chap. 1, The Combustion Wave). It is assumed that pressures capable of developing the flow velocities are available. Explosives used on gas- or oil-well fires illustrate this method. In one sense, the wind velocity accompanying the shock of the explosion increases the flow velocity of the gas above its burning velocity; from another viewpoint, the flame zone is physically removed from the unburned gases so suddenly that flame propagation cannot be sustained. In any event, extinguishment is effected if flame propagation is interrupted for as long a period as it would take for a flame to propagate normally through a zone.

The blowing out of a match also demonstrates this method. The draft must be strong enough to separate the flame from the match or to increase the flow velocity of the gases involved so that it exceeds their burning velocity. In addition, a cooling effect will be created.

Interrupting Flame Chain Reaction. The flame chain reaction is interrupted when interaction between free radicals and the fuel and oxygen stops. Free radicals in the flame zone ordinarily interact with the

fuel and oxygen so as to maintain or increase their number; thereby, the flame chain reaction is sustained. This self-propagation will continue unless sufficient free radicals are captured and made inert to interrupt the chain reaction. Halogenated hydrocarbons and dry-chemical extinguishing agents are used to capture the free radicals.

Much research remains to be done on this method, although much information is already available about its effects on gas-phase combustion. However, chain-reaction interruption alone will not extinguish class A fires, which the fire service deals with most often. At these fires, the burning material must still be cooled sufficiently or smothered to prevent further emission of flame.

Fire Extinguishers

Although many types of fire extinguishers are available, only those most commonly carried on fire-service apparatus are discussed. The figures on maximum horizontal range of stream actually have limited practical value, since the most effective use of extinguishers requires relatively close approach to the fire. Some newer types have a range of 45 to 50 ft, although it is obvious that a fire large enough that its heat prevents any closer approach would probably be too large for hand extinguishers.

The most recent classification for extinguishers consists of a numeral followed by a letter. The letter signifies the class of fire for which the extinguisher is suitable, and the numeral indicates the approximate fire-extinguishing potential. For example, a 4-A extinguisher is expected to extinguish twice as much fire in ordinary combustibles as a 2-A appliance. A standard extinguisher with a 2-A rating is normally expected to extinguish 100 sq ft of freely burning wood consisting of a 10- by 10-ft vertical panel with two layers of horizontal furring strips.

On class B extinguishers, the number indicates the approximate square-foot area of deep-layer flammable-liquid fire that can be extinguished when it is used by an average operator. A proficient operator might possibly extinguish twice as much. It is not a wise policy for an officer to assign an untrained man to the extinguisher.

Class C extinguishers are suitable for use on fires in "live" electrical equipment. They have as an extinguishing medium a material that is practically nonconducting when applied to the fire. They must also have at least a small amount of extinguishing effect on class A material.

Class D extinguishers are suitable for use on certain types of metal fires (Chaps. 3 and 7).

The letter classification shows the type of fire for which extinguishers are best suited, but it does not mean that they are valueless when used on other types. For example, soda-acid extinguishers are of value with

incipient fires on floors that are oil- or grease-soaked. Vaporizing-liquid extinguishers are frequently effective against small fires in ordinary combustibles.

Soda-Acid Extinguishers. The fire service is very familiar with the 2½-gal size, which weighs about 35 lb when fully charged and discharges an effective stream for about one minute. This type contains a solution of bicarbonate of soda in water in the outer shell and a small bottle of sulfuric acid in the neck of the extinguisher. Newer types are available in drawn brass or stainless steel and are tested by the manufacturers to 500 psi, assuring longer durable service and making possible increased nozzle pressure and stream range. Some types are provided with tough plastic nozzles, which resist damage and disclose clogging more readily. They can also be supplied with pressure-relief valves. Silicon bronze types are tested to 350 psi, less than the testing pressure of some other types. The silicon bronze type, in addition, is somewhat heavier than the stainless steel and drawn brass extinguishers of the same size. Other approved soda-acid extinguishers are made of a one-piece drawn brass shell with corrosion-proof interiors and deep-well silver-soldered bottoms.

Method of Operation. The extinguisher is inverted, and the stopple falls from the acid bottle. The chemicals mix, producing pressurized carbon dioxide gas, which forces the water through the hose and nozzle. Extinguishment depends mainly upon the cooling effects of the water solution. The stream is usually most effective if used close to the fire, but if necessary, it can be directed effectively from a distance of 30 to 40 ft horizontally. Direct the stream at the base of the flame, whipping slightly for greater coverage.

Suitability. Soda-acid extinguishers are effective on incipient fires in ordinary combustible materials (such as wood, paper, textiles, and rubbish), that is, class A fires where the quenching and cooling effects of water or water solutions are of primary importance. They are ineffective for fires in flammable liquids or greases in vats or open vessels, but they have limited value with fires on oil- or grease-soaked floors.

Maintenance. After extinguishers have been used at fires, care should be taken to render them harmless by properly releasing the pressure. Unreleased pressure can be dangerous at the fire or in quarters later, when the extinguisher is about to be refilled. When refilling, the sodium bicarbonate should be dissolved in lukewarm (not hot) water outside the extinguisher and then poured in.

These extinguishers should be recharged annually as well as immediately after each use. In recharging, all parts should be washed thoroughly with water and water drained through the hose. The annual recharge is advisable because the chemicals used deteriorate with age.

This type of extinguisher requires protection against temperatures

below 40° and above 120°F. They need protection against abnormally high temperatures because the heat causes the sodium bicarbonate solution to decompose slowly, releasing carbon dioxide.

Several times a year, at regular intervals, extinguishers should be examined for possible defects or clogged nozzles. Every five years extinguishers that have been in service for that period of time should be subjected to a standard hydrostatic-pressure test to ensure that they can still withstand the pressure that may be generated during operation. In such tests hand-type extinguishers are subjected to a pressure of not less than 300 nor more than 350 psi for a period of one minute.

Antifreeze solutions and wetting agents are not suitable for the soda-acid extinguisher, due in part to harmful interference with the chemical reaction.

Water Extinguishers. Water is the sole ingredient in these extinguishers, except that a calcium chloride solution may be used where the temperature is likely to be less than 40°F. Pressure to expel the water may be provided by pump, stored pressure, or a stored cartridge.

Pump-tank Extinguisher. The 5-gal pump-tank extinguisher is very familiar to the fire service. It has a built-in pump with attached hose and nozzle and weighs about 55 lb when full. The container has a handle for carrying. In back-pack types, designed for brush fires and other special uses, the tank is carried on the operator's back. The method of operation varies, but the invariably simple instructions are displayed on the tanks. These extinguishers can be discharged intermittently, and the force, range, and duration of the stream are dependent upon the operator. Horizontal ranges of 30 to 40 ft can be realized. The stream should be directed at the base of the flames, following them and working around the fire if possible. All types of these extinguishers are effective on incipient fires in ordinary combustible materials.

Calcium chloride solution can be used to protect the extinguisher against freezing. The chemical should be thoroughly dissolved in water (preferably cold) outside the extinguisher and then poured in through a fine strainer. Common salt must not be used, as it may corrode these extinguishers and make them dangerous to use. They should be checked frequently for defects. Pumping efficiency can be tested by operating the pump several strokes, discharging the water or solution back into the tank. At the time of the tests, which should be conducted at least once a year, a drop of thin lubricating oil should be put on the piston-rod packing.

Stored-pressure Extinguishers. Older types of the 2½-gal size weigh about 35 lb. Some newer types weigh 5 lb less, are tested to 500 psi, and are made of stainless steel with a finish designed to resist corrosion and oxidation. These extinguishers can be pressurized by air from any source

with 100 psi or more, such as a service station air chuck or tire-inflation valve on modern fire apparatus, or from nitrogen recharge units. On some types, the operator simply pulls the pin out of the locking position and presses the lever down. Others are operated by removing the hose from its position on the operating button and then pushing the button or by lifting a locking lever and squeezing both parts of the handle together. The stream has a horizontal range of 30 to 50 ft. It should be directed at the base of the flames, following them and working around the fire if possible. The extinguisher shuts down when the pressure on the lever or operating button is released. This is an important advantage, for the stream can be shut down and opened up intermittently as desired without the danger inherent in some other extinguishers. Stored-pressure water extinguishers are suitable for the same kinds of fires as soda-acid extinguishers.

These units should be recharged immediately after use, in accordance with instructions. Before it is recharged, the extinguisher should be inverted and the stored pressure released by pressing the lever or operating button. During the pressurizing process, after 125 psi (some have lower working pressures) registers on the gage, the extinguisher should be shaken so that the contents absorb the pressure, repeating the process if necessary, until the reading of 125 psi is constant.

Annual recharge is not necessary, since the visual gage will indicate that the extinguisher is in proper working condition. It is necessary to protect it against freezing or to add antifreezing ingredients.

Cartridge-operated Extinguishers. Some newer types are made of stainless steel and drawn brass, and both are tested to 500 psi pressure instead of the usual 350 psi. The expelling pressure is supplied by carbon dioxide cartridges. The extinguisher is bumped gently against the floor or wall to puncture the gas-retaining seal. The released carbon dioxide forces the water out, providing a stream with a horizontal range of about 40 to 50 ft. The cartridge is emptied at each operation, but it can be returned, at extra cost, to the manufacturer for recharging. These extinguishers are effective against the same kinds of fires as soda-acid and pressurized water extinguishers.

After use, the cap assembly should be removed, the extinguisher cleaned thoroughly, the hose blown through to make sure it is clear and free of leaks, and the extinguisher filled with fresh water to the filling mark. The cartridge should then be put in place and the cap screwed on tight. No annual recharging is necessary, but an inspection at least annually is in order. At such times the water level should be checked and the carbon dioxide weighed. If the loss in weight is more than the amount specified in instructions on the name plate, the cartridge should be re-

placed. Some manufacturers recommend that the cartridges should be weighed at least semiannually.

These extinguishers should be protected against low temperatures unless antifreeze ingredients have been added. Some antifreeze-containing types are made of drawn brass or silicon bronze, tested to 500 and 350 psi, respectively.

Foam Extinguishers. The fire service is most familiar with the 2½-gal extinguisher, weighing about 35 lb when charged, with a horizontal range of 30 to 40 ft and an effective discharge period of about one minute. In the outer compartment of the extinguisher are bicarbonate of soda and a foam-stabilizing agent dissolved in water. In the smaller, inner compartment is an aluminum sulfate solution. Some newer foam extinguishers are made of stainless steel, drawn brass, or silicon. Those made of silicon are tested to 350 psi and the others to 500 psi. One type features a pressure-relief valve.

Method of Operation. The extinguisher is inverted, and the two solutions mix and produce carbon dioxide gas. The pressure of the gas not only expels the liquid from the extinguisher but also forms bubbles, which are toughened by the foam-stabilizing agent.

When applied to fires in flammable liquids in depth, such as in a dip tank, the stream should be directed against the side of the tank so that it will flow over the surface rather than plunge into the burning liquid. If the foam is immersed in the burning contents, it will rise to the surface with the flammable liquid burning on it and may be broken down rapidly. When application against the side is not possible, the stream should be arched so that the foam is deposited as gently as possible around the surface of the liquid. This method will only be effective, however, when the fire is well within the range of the extinguisher, as the heat of the flames will break down the foam more rapidly when it is applied in the form of divided "drops" (the stream breaks up when applied from a distance). At ordinary room temperature, a 2½-gal extinguisher will produce 20 to 25 gal of foam. To utilize the foam more effectively, the operator should, if possible, walk around the fire while directing the stream in order to reduce more quickly the intensity of the flames and the breakdown of the foam during application.

Suitability. Foam is best used on flammable liquids contained in tanks or vats or in cases where the flammable liquid may have spilled but is not flowing. It is less effective where the flow of an underlying liquid can break up a smothering layer of foam. Foam may be completely ineffective on fires in liquids flowing from broken lines.

Unless it is specifically noted on the name plate, these extinguishers are not recommended for use on fires in alcohol-type (polar) solvents,

Although primarily intended for use on class B fires, these extinguishers can be effective on small fires in ordinary combustible materials.

Maintenance. These extinguishers should be protected against freezing and should not be located where the ambient temperature will exceed 120°F.

Recharging is necessary immediately after use as well as annually. In the recharging process, all parts should be thoroughly washed with water and water drained through the hose.

Antifreeze solutions, such as calcium chloride, common salt, etc., should not be used in these extinguishers, since they may unfavorably affect the chemical reaction or may corrode the extinguisher, making it dangerous to use.

Extinguishers should be examined as often as necessary to ensure the prompt detection of any defects. The five-year hydrostatic test is recommended for this type of extinguisher.

Firefighters should be instructed how to use this extinguisher effectively. They should also be impressed with the importance of charging it properly, since the quantity and quality of foam produced depend upon the care taken in mixing the charge as well as upon the ingredients and the temperature at which the extinguisher is operated.

Loaded-stream Extinguishers. The 2½-gal size weighs about 43 lb when charged. The extinguishing agent is an alkali-metal salt solution that has a freezing point of —40°F. The expelling force in the newer models may be supplied by pressurized air, in the manner described previously for pressurized water extinguishers, or by a cartridge.

Method of Operation. Operation depends upon the source of expelling force. If the source is pressurized air, the extinguisher may be operated in an upright position like air-pressurized types; if the source is a carbon dioxide cartridge, the operation is similar to that of other cartridge-operated extinguishers.

At class A fires, the stream should be directed at the base of the flames. With class B fires, the contents should be discharged against the inside wall of the container, just above the burning surface, and not into the burning liquid. Where possible, the operator should walk around the container while directing the stream so as to get maximum coverage. The horizontal range of the stream is 40 to 45 ft (45 to 60 ft with one type), and the duration of the stream from the 2½-gal size is about one minute.

Suitability. These extinguishers are suitable for class A and B fires. The effect of loaded streams is different from that of other agents. In class A fires the flame is put out rather suddenly, and there is a pronounced fire-retarding effect. The effect on certain class B fires has not yet been completely explained. In the past experts suggested that there was a chemical

reaction tending to inhibit oxidation, but it is now thought by many that the effectiveness of loaded-stream extinguishers is due to a chemical chain-breaking action.

Maintenance. These extinguishers are maintained like plain water types; they require no protection against freezing but should not be located where the ambient temperature will exceed 120°F. At recharging, all parts should be washed thoroughly with water and water drained through the hose. All water should be removed from the hose to prevent clogging and to minimize the possibility of clogging in the nozzle due to freezing.

No annual recharge is required; only visual check of pressure, as indicated on the gage, and of fluid level is needed. If cartridges are used, they should be weighed periodically as explained in the discussion of cartridge-operated water-extinguishers. Some of the late models are made of stainless steel and are tested at 500 psi.

Vaporizing-liquid Extinguishers. These devices come in two basic designs: (1) extinguishers in which the liquid is expelled by manual pumping; (2) extinguishers in which the liquid is expelled by nitrogen gas pressure or by pressurized air within the extinguisher. The former type, in the smaller sizes, is familiar to the fire service. The 1-quart (qt) size weighs 7 lb; the 2-qt size weighs about 16 lb. The extinguishing agent is a specially treated carbon tetrachloride or chlorobromomethane, both of which are electrically nonconductive. Commercial carbon tetrachloride is not suitable for use in these extinguishers since it may contain traces of water, which could react with the carbon tetrachloride to form hydrochloric acid, resulting in harmful corrosion.

Method of Operation. By manual operation of the double-acting pumps, a reasonably continuous stream of liquid can be discharged with a horizontal range of 20 to 30 ft. For class A fires the stream should be directed at the base of the fire. Heat causes the liquid to vaporize and form a smothering blanket of vapor, which is heavier than air and will not support combustion. At class B fires the liquid is directed at the inside of the container above the level of the burning surface. The resulting smothering blanket covers the burning surface and extinguishes the fire. The stream should not be directed into the burning liquid. Again, for maximum coverage and effect, the operator should walk around the fire while operating the extinguisher. Best results are realized if the stream is used close to the fire, but it can be directed from 20 to 30 ft away (30 to 40 ft for larger sizes). Firefighters should be trained to take proper precautions when these extinguishers are used in confined spaces. It may become hazardous to breathe the gases or vapors liberated or produced, particularly when carbon tetrachloride comes in contact with hot metal.

Suitability. These extinguishers can be used on class A fires, but they are not very effective compared with water. Their cooling effect from evaporation is only approximately one-tenth that of water.

They are effective on class B fires in which the gas formed by the liquid extinguishing agent may be retained as a blanket on the burning material. Such fires are limited in size to rather small quantities of flammable liquids, greases, etc., in vats or open vessels.

Vaporizing-liquid extinguishers are best used for protection against electrical fires, and they are highly effective against fires in cars, motorboats, and engines of various kinds.

Maintenance. These units should always be kept full, and they should be refilled immediately after use. In addition, they should be partially discharged and refilled annually, with fresh liquid added. Only liquid furnished by the manufacturer should be used to wash out the extinguisher or to recharge it. At the annual inspection all parts should be checked for possible defects. The pumps can be tested by discharging some of the liquid with the stream directed alternately upward and downward.

This type of extinguisher should be carefully checked at rather frequent intervals to ensure sufficient liquid. One modern type features a liquid level port to facilitate such a check. Heavy sloshing of the liquid indicates a need for refilling. Hydrostatic tests are now recommended for these extinguishers of the pressurized or cartridge-operated types except for factory-sealed disposable (nonrefillable) containers.

Units employing stored air pressure either are provided with a built-in pump for maintaining the air pressure or obtain the air from external sources, as air-pressurized extinguishers do. All are equipped with gages to indicate the pressure. One such unit is operated by turning a handle that simultaneously opens both air and liquid containers. Another type is operated by pulling up on a lever, admitting air pressure to the liquid container and thereby releasing liquid to the hose and nozzle.

These extinguishers have a freezing point of about —50°F and include a corrosion-inhibiting ingredient. They should not be exposed to ambient temperatures of more than 120°F.

Carbon Dioxide Extinguishers. These extinguishers consist of a metal container under pressure, liquid carbon dioxide, a valve to release the carbon dioxide, and a horn for applying it to the fire. The liquid carbon dioxide is under pressure of 800 to 900 psi at normal room temperature. Containers must be sufficiently strong (some are tested to 3,000 psi to meet Interstate Commerce Commission requirements) to withstand such constant pressure.

From the valve a tube extends to the bottom of the extinguisher so that only liquid carbon dioxide will reach the discharge horn until about

80 per cent of the contents (at room temperature) has been discharged. After that, carbon dioxide gas will be discharged. Upon release from the container, the liquid carbon dioxide expands and is chilled to a low temperature; approximately 30 per cent of it is converted into the solid state (carbon dioxide "snow," or "dry ice"). The horn surrounds the jet of carbon dioxide where its velocity is very high to prevent the entrainment of air, which could dilute the stream and reduce its effectiveness. When the carbon dioxide stream has reached the open end of the horn, the velocity has been reduced to such an extent that air entrainment is no longer a serious problem. On the sizes most used in the fire service the horn is attached to the end of a hose capable of withstanding high pressures.

Method of Operation. A trigger, lever, or other mechanism is used to start the discharge of a cloud of carbon dioxide gas and some "snow" (about 30 per cent). The best results are obtained by applying the discharge as close to the fire as possible, first at the near edge and bottom of the fire and slowly progressing forward as the fire is extinguished. The horn should be moved from side to side during the discharge, which should be continued even after the fire is out to prevent reflash by coating the hot surface and any glowing material present. The effective range for the streams varies from 3 to 8 ft, depending upon the size and design of the extinguisher. On flammable-liquid fires, the discharge should be applied as described above, with the intent of sweeping the flames off the burning surface.

The cooling effect of carbon dioxide "snow" unquestionably is a factor in preventing flashback in small fires, but this cooling effect is negligible compared with that of water and is unimportant in extinguishing fire compared with the smothering effect of carbon dioxide.

Suitability. Since carbon dioxide is essentially nonconducting, these extinguishers are suitable for use on electrical fires when their horns are also nonconductive. They are effective on class B fires when the discharge can be applied to sweep the flame from the burning surface and when it can be applied to develop an effective smothering blanket. By itself, the sweeping of the flames from the burning surface would not necessarily achieve permanent extinguishment. If, for example, the surface temperature of the material remains above that at which it will give off sufficient vapors to support combustion, and if the liquids involved have a low flash point, reignition is possible. Permanent extinguishment is ensured by continued application of the discharge, subsequent cooling of the surface, and development of an atmosphere in which combustion can no longer be sustained. Reduction of the oxygen content to 15 per cent should suffice for the fires referred to.

The carbon dioxide extinguisher is of limited value with surface fires

of the class A kind. An important advantage is that the gas is clean, dry, and harmless to material and equipment. It is not effective on deep-seated fires, however. It is particularly useful for fires in automobiles, motorboats, and engines of various kinds. When it is used in unvented places, there may be harmful effects from breathing the vapors or gases liberated.

Maintenance. These extinguishers are capable of complete, uninterrupted discharge at temperatures of —40°F. At temperatures below 0°F, blockage may occur, rendering the extinguisher useless if the discharge is interrupted one or more times. This condition corrects itself without any damage to the extinguisher after a period of time dependent upon the ambient temperature.

Extinguishers should be kept full at all times. They should be refilled after use even though only partially discharged. Weighing is an accurate way of determining whether they are full. An extinguisher that shows a loss of 10 per cent or more of the rated capacity stamped on it should be recharged.

It has been recommended that these extinguishers should be examined at regular intervals—several times a year—for possible defects, and at least semiannually they should be weighed and otherwise checked. These recommendations apply to the extinguishers on apparatus as well as to those held in reserve. The units should not be stored where temperatures exceed 120°F, unless otherwise noted on the name plate.

Extinguisher cylinders should be hydrostatically retested every twelve years in accordance with Interstate Commerce Commission requirements to determine if they are satisfactory for continued use.

Dry-chemical Extinguishers. The extinguishing agent is a dry-chemical mixture composed primarily of specially treated sodium bicarbonate with materials added to produce water repellancy and free flowing. The expelling force is provided by carbon dioxide, nitrogen gas, or dry air. Pressures vary from 150 to 350 psi, and the effective stream range is 10 to 25 ft, depending upon the size and design of the extinguisher. A 4-lb type discharges about ½ lb of powder per second. The extinguishing effect of dry chemical powder is discussed in Chap. 3.

Method of Operation. In the cartridge-operated type, the released gas exerts pressure on the dry-chemical chamber and the chemical is expelled. The gas may be released by turning a hand wheel to unseat a valve or by operating a small lever or inverting and bumping the extinguisher on the floor to puncture a seal disk. The flow of chemical is controlled manually by a valve located either at the body of the extinguisher or at the nozzle.

In a pressurized dry-chemical extinguisher, both the dry chemical and the expellant are stored in a single chamber. Being under constant pres-

sure, the powder is always in suspension, thereby ensuring desirable free flow. The flow is controlled manually by a squeeze-grip nozzle or a single-finger control.

With fires in flammable liquids and electrical equipment, the discharge should be directed at the base of the flames. It is best to attack the near edge of the fire and then progress forward, moving the nozzle rapidly with a side-to-side sweeping motion. The electrical conductivity of dry chemical is about equivalent to that of air. When extinguishers with a relatively high-velocity nozzle are used, the initial discharge should be from not less than 6 to 8 ft from the fire, in order to prevent splashing if the flammable liquid is deep.

In surface fires involving textiles, the discharge should be directed at least 3 to 4 ft above the flame from a distance of 8 to 10 ft. The dry chemical will then coat surface areas ahead of flash fires, which tends to retard the progress of the fire. After this application, the discharge can be directed at the initial fire with no danger of spreading the fire by blowing burning particles about. In smoldering or subsurface fires, water in some form, preferably spray, should be on hand to extinguish any residual fire.

Suitability. Dry chemical powder is nonconductive, nontoxic, noncorrosive, and practically nonfreezing. Efforts are being made to develop a chemical powder that would be more effective on class A fires. One result is a commercial ABC powder, *intumescent powder,* which contains fireproofing salts designed to prevent afterglow in solid fuels; another commercial ABC powder contains ingredients that prevent reignition by foaming. Still other improvements can be expected.

Dry-chemical extinguishers are effective on class B and C fires and are being used more against class A fires in textile fibers such as cotton, but there are limitations when the fires are deep-seated.

Maintenance. Extinguishers should contain the specified weight of dry chemical at all times. In the cartridge-operated type, cartridges should be fully charged at all times. Reweighing will determine whether the cartridge is fully charged. Some cartridges have a pressure gage to indicate whether the required contents are maintained. In pressurized extinguishers, adequate expelling pressure must be maintained at all times and can be checked by pressure gages.

Extinguishers should be refilled immediately after use, even though only partly discharged. Before recharging, the hose should be cleaned of all dry chemical.

These extinguishers do not need to be protected against freezing—they may operate effectively at —40°F—but they should not be kept where the ambient temperature will exceed 120°F, unless otherwise noted on the name plate.

Extinguishers should be checked at regular intervals—several times a year—for possible defects. Cartridge-operated extinguishers should be checked to make sure that the dry chemical powder flows freely. At least semiannually, all cartridges should be removed and weighed accurately to detect any possible leakage. If the weight loss exceeds that permitted by the instructions on the name plate, a new cartridge should be provided. The cartridges that have a gage and the pressurized extinguishers should be examined to determine that the pressure is within the operating range.

The hydrostatic test is now recommended for dry-chemical extinguishers every ten years except for factory-sealed disposable (nonrefillable) containers.

It is significant to note the much improved rating of the dry-chemical-powder extinguisher in the comparatively recent revised classifications over the rating given these extinguishers in 1942.

Foam-compatible Dry Chemicals. Common dry-chemical extinguishers cannot be used successfully with foam for spill fires of flammable liquids. Previously used dry chemicals caused a rapid breakdown and collapse of the foam blanket. However, there is a new foam-compatible dry chemical with an alkali bicarbonate base; it is light green in color and can be used with mechanical or chemical foam of high or low expansion in standard extinguishers 20 lb and up in size. Such extinguishers have a green body.

Suggestions for Use. The use of extinguishers in industry or institutions should be governed by the following considerations:

1. The type of extinguisher that can best cope with potential hazards should be selected. Advice from the neighboring firehouse should help in the selection. The fire service can also advise about the number of extinguishing units required. The number needed will vary with the presence or absence of sprinkler or standpipe systems, the nature of the occupancy, the construction, the public fire service available, etc. Of course, the classification of the extinguisher is an important factor.

2. The physical limitations of the people available to operate the extinguisher should be considered in its selection. In larger organizations operation should be assigned to specific individuals, with substitutes to cover in the event of sick or vacation leaves. Selected personnel should be instructed about suitability of extinguishers, method of operation, storage, maintenance, any associated hazards, and recharging processes. A good occasion for instruction is the periodic examination, when extinguishers are usually discharged. Personnel should know the limitations of extinguishers and should be instructed to notify the fire department as soon as possible if fire breaks out.

3. Extinguishers should be placed in a conspicuous and accessible

location, and any change should be quickly made known. They should be hung at a reasonable height and should be easily removable from the wall. They should be close to potential hazards but not so close that it would be difficult to reach them in the event of fire.

4. A sufficient quantity of charges or needed materials should be on hand to ensure multiple operations or to recharge the extinguisher at once, if necessary. Only the chemicals or ingredients stipulated by the manufacturer should be used.

5. Extinguishers should be examined regularly at least several times a year to check for possible tampering, damage, or clogging of nozzle and to make sure they are full. If there is doubt about their effectiveness, they should be checked by the manufacturer. Records should be kept of all examinations and inspections, showing results and the name of the examiner. Hydrostatic tests should be conducted as required.

6. In some areas, legislation prohibits the use of certain types of extinguishers because of the toxicity hazard. Inquiries definitely should be made on this point.

7. Signs legible for a distance of at least 25 ft should indicate the class or classes of fires for which the nearby extinguisher is suitable, and personnel should be instructed about the classes of fires.

3

Fire-extinguishing Agents

The primary extinguishing agent is water. It is effective in the great majority of cases, it is available in many places in sufficient quantity, it is comparatively inexpensive, and it has excellent properties of specific and latent heat. It can be used in master streams, with hand lines, as fog, and with foaming agents, wetting agents, and additives.

Recent tests have shown that additives can increase the extinguishing power of water *by retarding runoff*. In one case, the addition of 1 per cent of a certain material increased the viscosity of water and doubled the extinguishing effect. Addition of 0.05 per cent of aluminum powder increased the effect by a factor of 10. Even better performance results when the aluminum powder is in suspended solution with the water instead of merely floating on top. The mechanism involved here is explained as follows: during a fire, energy is transferred from the flaming zone back to the surface of the fuel mainly by radiation; when suspended aluminum powder is used, it forms a reflective shield in the intermediate zone, thus reflecting a large part of the radiant heat away from the fuel; the water, however, still has a cooling effect, and the combined action reduces the supply of combustible gases to the flaming zone and thus permits extinguishment in a much shorter time.

Efforts are being made to develop other additives that will improve the extinguishing power of water, especially in the form of high-expansion foam. In Great Britain some research has been aimed at using humidified exhaust gases from jet engines to help control fires, but the

results so far are inconclusive. Many chemical extinguishing agents are also the subjects of experimentation.

Water

Master Streams. A master stream is a heavy-caliber stream with pressure and range adequate for fires too large to be fought with hand lines. Such streams, with their large volumes of water (up to 3,000 gal per minute, and even higher), call for larger-sized hose, and siamesed lines in some cases. Because of the high nozzle pressures, particularly with solid streams, mechanical appliances are used to control and operate the streams. Master streams are frequently required to combat the large fires that cause such great loss in property (only $\frac{1}{3}$ of 1 per cent of the total fires cause over 60 per cent of the property destruction in this country). Obviously, then, a knowledge of master streams and their appliances is important to firefighters. Essential characteristics of master streams include reach, penetration, sweep or mobility, and control.

Reach. A master stream must have a reach sufficient to propel water far enough to exert effective extinguishing action on the fire or protective action on exposures. Reach is affected by the amount of water discharged and other factors. Excessive nozzle pressure may result in a discharge that is too much for the nozzle to handle well, which impairs the reach of the stream. Reach will also be adversely affected if the nozzle is defective in the interior form or if the inner surface is not smooth. Given the same velocity, the smaller the nozzle size, the shorter the reach. Excessive pressure will break up a small stream more quickly than a large one. Theoretically, the greater the velocity at the nozzle, the greater the reach from the same size nozzle. But there is a maximum effective velocity beyond which the stream tends to break up into fine particles, causing rapid dissolution of the stream in midair.

Wind has an effect on reach. A faint tail breeze will increase horizontal reach by about 10 per cent in some cases, and a moderate tail breeze will lower vertical reach by 10 to 15 per cent. A head breeze will raise the vertical and shorten the horizontal reach, and a strong head wind will cut off the stream sharply. If it increases in velocity, it will destroy the stream at the tip by turning it into spray, which is driven to the rear of the nozzle. A strong tail wind will carry the water forward but break it up into rain and spray. In adverse winds of 10 or more mph, the effective stream range may be reduced by as much as 40 per cent.

Wind also has a strong effect on resistance; tail winds reduce resistance, and head winds increase it. In both cases, the stream wastage is increased.

The foregoing observations were originally made on solid streams. Obviously, the effect of wind on fog streams is more pronounced, so much so that strong head winds could render fog streams practically useless. However, tail winds may increase the effectiveness of fog streams even more than that of solid streams.

When the water leaves the nozzle, gravity causes it to fall toward the earth. The stream then takes on a parabolic curved form, which increases the surface exposed to friction and thereby decreases the reach. A stream operated from higher ground will have greater reach than the same stream operated from a lower level. The horizontal effective reach is at its maximum at an angle of 30 to 34°. Above that angle, it decreases.

The use of ordinary wetting agents reduces the reach of streams because the surface tension of the water is reduced. As a result, such streams will break up more quickly.

Penetration. The water of a fire stream must get close enough to the burning material to absorb heat at an effective rate. Obviously, other conditions being equal, the stream with the greatest striking power will develop the greatest penetration. Penetration will be adversely affected by piled-up stock, partitions, walls, and street conditions that prevent favorable placement of apparatus. Stream penetration is also affected by wind, velocity, angularity, etc., which affect reach.

An effective stream is one that places 90 per cent of the water within an imaginary 15-in. circle when it reaches the seat of the fire (or 75 per cent of the water within a 10-in. circle).

Sweep. Mobility has been greatly improved by the advent of metal aerials and their ladder pipes, with their important advantages. It is now possible to place the nozzle of a ladder pipe directly in a window and sweep the floor or fire area. All-mechanical, remote control of the modern ladder pipe enhances this advantage. Modern metal-aerial ladders are sufficiently strong to permit the operation of ladder pipes at the tip of the aerial (fly) and at an intermediate position.

Overextension at angles below 60° from horizontal can be guarded against by placing the center line of the truck not more than 35 ft from the fire building. If overextension and frontal coverage do not present problems, the center line of the truck can be placed nearer the building.

Control. Stream direction and pattern on ladder pipes are governed by manual, hydraulic, or electric controls.

Manual controls can be manipulated either from the ground or at the nozzle location on the ladder tip. The former control elevation of the stream via rope guidelines; to direct the stream right or left, it is necessary to rotate the turntable. The operator at the nozzle location can regulate the pattern of the stream as well as its elevation, can swing the stream right or left to a limited extent (about 15° either way), and, above all, can observe whether the stream is being used effectively.

Newer-model ladder pipes are portable and may be attached to the ladder at any point. In some fire departments, the intermediate nozzle is permanently fixed.

Hydraulic controls are operated from the turntable. Two simple switches control stream elevation and stream pattern, from full fog to straight stream. Such ladder pipes cannot be thrust over backward, as has happened with rope-controlled nozzles. All operations can also be controlled manually.

By means of pushbuttons at the electrical control panel on the turntable pedestal, the operator can control the angle of operation and pattern of stream from 90° fog to straight stream. Remote control of master-stream devices is one of the most progressive accomplishments in fire-stream control appliances in the last 50 years.

The elevation and rotation of portable monitors, also known as deluge guns or portable turrets, and by various trade names, are controlled by hand, by a worm and gear, or by combinations of both. Once it is set up, one man can control the operation. Such devices also have a safety notch or lock in the elevating mechanism to maintain the nozzle at the minimum angle necessary to keep the appliance stationary. If the elevation is less than the safe angle maintained by the lock, the nozzle thrust under pressure may cause the entire device to move backward and whip out of control. Portable monitors are refinements of their predecessors, the deluge sets, but, unlike them, can be used as fixed guns. Some devices can furnish straight, fog, fog-foam, and straight foam streams. In addition, some trucks carrying dry chemical powder are equipped with turret nozzles that can discharge 25 lb of dry chemical per second and have a range of 90 ft.

Remote control and direction innovation can be applied with equal success to portable turrets or deluge nozzles. With slight modifications, control levers can be made portable, thus permitting a deluge gun to be operated by remote control from a safe area.

Conclusions. Members of the fire service must be trained in supplying and using master-stream appliances, since these devices are so important in fighting the largest and most costly fires. Preplanned procedures should be developed for supplying master-stream appliances under various conditions. When these appliances are needed, those at hand should be utilized promptly and other needed apparatus should be called for at once. Correct anticipation of the need for master streams and prompt operation might permit control of fires in the earlier stages.

Vantage points from which the heavy-stream appliances are operated should be selected quickly but carefully, with consideration given to the order of priority in covering exposures (Part 2). Hydrants and mains should be selected carefully and proper authorities notified to increase water pressure, if that is deemed advisable. The streams should be super-

vised to ensure appropriate reach, angularity, penetration, and mobility. Streams no longer serving useful purposes should be promptly shut down. Particularly in the early stages of an operation, master-stream appliances should be used to maximum advantage. The advantages of remote control and direction innovation with portable turrets or deluge nozzles as well as with ladder pipes and ladder master streams should be kept in mind. At all times, operations should keep within the performance limits of available pumping equipment and water supply. All necessary precautions should be taken if fire personnel may be endangered while putting master streams to work.

Hand Lines. Hand-line streams can be either fog or solid, but this discussion emphasizes the latter (see below, Fog). Practically everything said about the factors affecting the reach and penetration of master streams applies also to hand lines. Mobility, nozzles in use on hand lines, nozzle pressures, hose size, the relationship of nozzle size to hose size and length of the line, and procedures for stretching hand lines are important factors.

Mobility. The characteristic mobility of hand lines is improved at times by temporarily shutting down the nozzle when moving from place to place, floor to floor, or from ladders into floor areas. This requires control nozzles. Sometimes mobility must be sacrificed, but never to the point of inefficiency. For example, when operating from the vantage point of a fire escape, it may be helpful to lash the line, thereby simplifying its handling.

Gate valves should be used (usually one length from the nozzle) when control of the water supply permits prompt replacement of cellar pipes and distributors by hand lines.

Hand-line Nozzles. Nozzles are classified according to whether they are of the control or open type. Control nozzles are used with 2½-in. to booster-size hose, generally in interior operations and particularly where maneuverability is desired. Some control nozzles are all-purpose; that is, they can provide solid or fog streams. Certain kinds can be used with applicators (see below, Fog). These nozzles can deliver solid streams or fog streams of high or low velocity. If electrical equipment is involved or exposed, there is a danger in using an all-purpose nozzle because it may be accidentally switched from fog to solid position.

Open nozzles are generally used for exterior operations, and hence more often with larger-sized hose, because such operations frequently indicate a more extensive fire (excluding grass or brush fires, which may be extensive but do not necessarily require larger open-nozzle streams).

Nozzle sizes range from 1¼ in. to the smallest size (3/16- and ⅜-in. tips) used on booster pump lines. Streams requiring nozzles larger than 1¼ in. (excluding foam streams) belong to the master-stream group.

The nozzles presently available can be used for a variety of purposes;

they are effective for class A fires, with fog for class B fires, with low-velocity fog for occupancies with radioactive materials, etc.

Suggested Nozzle Pressures. Some authorities state that 40 to 60 lb of pressure will give good streams for hand lines. However, the author recommends 30 to 35 lb as more feasible for interior operation with 2½-in. hand lines. Higher pressures make it more difficult to handle the nozzle and make the hose line stiffer, greatly reducing mobility. For interior lines of 1½-in. hose, nozzle pressures of 20 to 30 lb generally suffice to provide desired reach and penetration; where hose of that size is adequate, streams of great force are not usually essential. Some departments use extremely high pressure on special fog streams, but effective use of such streams calls for good judgment and training. The very high-velocity fog, for example, if applied from the windward side of a grass fire, could cause rapid spread by driving the convection currents ahead, with blowtorch effect. However, its advantages far outweigh any disadvantages, and it only requires careful use.

Hose Size. Hand lines include all hose sizes between 2½ in. and the ¾-in. booster-line hose. For washing-down purposes, 2½-in. hose frequently is reduced to 1½-in. hose in conjunction with ½- or ⅝-in. tips or spray nozzles. The hose size chosen will naturally be influenced by the objective of the line, the water-supply situation, and the manpower, apparatus, and equipment available and on hand. When 1½-in. hose is used alone, its limitations should be kept in mind since medium stretches using a ¾-in. nozzle with only 30-lb pressure on the nozzle could require an engine pressure of about 175 lb. Such pressure can be the cause of a hose burst. In addition, when the 1½-in. line is the first to be stretched, it should be backed up in many cases by a 2½-in. line. To minimize the possibility of hose burst from high pressure, it is common practice to extend two 1½-in. lines from a single 2½-in. line by means of a wye connection.

Relationship of Nozzle Size to Hose Size and Length of Line. Up to six lengths of 50-ft hose is a short line, six to twelve lengths is medium, and twelve lengths and more is long. For a short line, a nozzle one-half the diameter of the hose can be used; that is, a maximum of 1¼ in. for 2½-in. hose. For medium lines, the largest size nozzle should be the next size smaller than one-half the hose diameter; that is, 1⅛ in. for 2½-in. hose, or 1⅜ in. for 3-in. hose. For the long line, the largest nozzle should be the second size smaller than one-half the hose diameter; that is, 1 in. on a long stretch of 2½-in. hose. These recommendations apply to plain nozzles and not to nozzles for fog or foam lines or to the fixed nozzles of booster pump lines.

Procedures for Stretching Hand Lines. In addition to selecting the right-sized hose, it is important to see that sufficient hose is being stretched. Too much hose delays getting the stream in operation, in-

creases the engine pressure due to greater friction loss, offers greater obstruction when additional lines have to be stretched, and, in general, creates unnecessary confusion. Too little hose is, of course, even worse, since the delay in getting the stream in operation will be longer. To stretch the correct amount of hose requires some knowledge of the location of the fire. In some cases, officers who have failed to locate the fire have ordered lines into the wrong building. Moreover, such an officer would not know if the fire was between the occupants and their means of escape, and therefore would not know if there was a life hazard. In addition, the location of the fire may influence the size of hose selected (Chap. 5). There are advantages to stretching two lines at the same time when fire operations begin, particularly by the first pumper on the scene. The first line should be supplied and made ready as soon as possible, and an incoming unit can use the other line, with an important saving in time and effort.

Preplanned procedures for stretching hand lines are numerous, and they are invariably designed to meet the needs of the individual community. Usually, the fire can be handled by a single line or two from a booster pump. Procedures are planned accordingly so that apparatus carrying booster equipment can be used to maximum efficiency. Pumpers so equipped can drop off feed lines from a water-supply source and proceed to the fire building without delay. There, lines fed from the booster tank are quickly stretched and operated. Incoming pumpers can supply the feed lines if needed. The length of the feed lines may be affected by the size and amount of hose available, the possibility of siamesing lines, the available water-supply pressure, the location and extent of the fire, and other factors.

Fog. In order to exert any practical extinguishing effect, the droplets of a water spray must have sufficient carry (trajectory) to travel from the source of the spray to the heated area surrounding the fire, and the droplets arriving there must arrive with sufficient kinetic energy (velocity) to overcome the turbulent hot gases moving upward and away from the fire. Under comparable conditions of pressure and temperature, the density of water vapor is only 0.62 that of air. In some cases, the updraft of heated gases is less of a problem. For example, the inflow of gases at the base of the fire can be utilized to carry water vapor and water droplets to the seat of the combustion.

In order that the droplets may have the necessary reach or carry, and to overcome the usually prevailing updraft from the fire, it has been calculated from the extensive and useful research on the characteristics of water droplets that the optimum diameter for extinguishment is of the order of 350 microns (a micron is a very small unit of length, equal to 0.00003937 in. or 0.001 mm). In some experiments, droplets smaller

than 350 microns achieved extinguishment. Various factors, such as ventilation, confinement of the fire, kind of material burning, gravitation, prevailing drafts, distance to be traveled by the droplets, and method of application (vertically downward or horizontal), may affect the optimum diameter.

The establishment of a means of describing or characterizing water sprays used for extinguishing fires is an important research development. More scientifically manufactured fog and spray nozzles, designed to deliver water droplets of optimum diameter appropriate for various fires, may result.

Advantages. Fog can be used effectively with master-stream appliances, with wetting agents, and also with foam. It has greater and quicker absorption of heat per gallon than plain water. Water has its maximum cooling and extinguishing effect when applied as a cold fog and evaporated into steam. One pound of water applied at 60°F and evaporated into steam at 212°F has a cooling effect of 152 Btu $(212 - 60) + 970.3$ Btu, the specific heat plus the latent heat. *Specific heat* is the heat (thermal) capacity of a substance and is the number of British thermal units required to raise the temperature of one pound of a substance one degree Fahrenheit, or the number of calories required to raise one gram one degree centigrade. Water is a valuable extinguishing agent mainly because its specific heat is higher than that of other substances. *Latent heat* is the quantity of heat absorbed or given off by a substance in passing between the liquid and gaseous or the solid and liquid states, and it is measured in British thermal units or calories per unit weight. The latent heat of water (normal atmospheric pressure) at the freezing point (32°F) is 143.4 Btu per pound; at the boiling point (212°F), it is 970.3 Btu per pound. It is substantially greater than that of most other common substances.

Theoretically, fog applied at 100°F would more quickly reach the temperature at which the benefits of its latent heat are realized than would fog applied at 50°F. Quantitatively, however, 50 Btu less per pound of water used would be absorbed by the fog applied at the higher temperature.

Fog causes less water damage to property and the contents of fire buildings. This has a favorable effect on the public, as the salvage problem is simplified and business can be resumed and homes reoccupied more quickly. In addition, fires are extinguished more quickly.

Further advantages of fog are as follows: it reduces smoke toxicity; one man can handle nozzles since fog exerts considerably less pressure reaction at the nozzles than solid streams with comparable pressures; there is less drain on the public water supply; directing the fog toward the exterior through selected openings will effectively ventilate enclosed

and windowless areas; there is less chance of destroying arson evidence with fog; it can be used effectively on some class B fires, exerting both a smothering and a cooling effect; it increases the effectiveness of apparatus with booster equipment, stretching the amount of water in tanks; it can be used successfully in fixed systems; it protects the firefighter who is advancing or operating lines in hot spots.

In conjunction with the Navy all-service nozzles, fog can be used very effectively with applicators of various sizes. For example, it can be used to combat fires in ceiling spaces. Openings can be made by regular 6-ft or larger hooks for the insertion and use of applicators. The length of the hook to be used varies with the height of the ceiling. With this method, ceilings do not have to be pulled at an initial stage. Openings must be made at strategically selected spots, and the application of fog must be controlled as to time and volume to prevent the ceiling from being blown down by the expanding steam and to allow the expanding steam to work effectively on the fire in the ceiling area. Ceiling openings should follow a systematic pattern in order to cover the area as advantageously as possible. An additional and important advantage of this operation is that the fog, as it vaporizes to steam, follows the fire through hidden channels, exerting a powerful smothering and cooling effect and thereby minimizing the possibility of vertical and horizontal extension. Solid streams can be held in readiness if deemed advisable and, as a matter of fact, are available simply by removing the applicators. Pulling ceilings and then hitting the exposed fire with solid streams is a slower and less effective method, and the possibility of vertical and horizontal fire extension is greater.

Applicators can also be used through openings in walls. The openings need be only large enough to insert the head and pipe extension (preferably 45° rather than 90° angle) of the applicator and to permit sufficient freedom for effective use; they should be placed to ensure the fog reaching areas in which vaporization will occur. Such openings can be readily made in walls or partitions by rescue companies employing concrete breakers or similar equipment. Applicators may then be inserted from a room or structure adjoining the fire area and fog applied to otherwise inaccessible spots. Care must be exercised to warn men operating in the interior of the fire structure to withdraw in order to avoid injury from the expanding steam. This operation is particularly appropriate where one or more floors (lower) are involved in such a way that roof ventilation is of little or no assistance and an interior attack is made unusually difficult by heat, smoke, and restricted access.

This technique is recommended as a supplement to an interior attack already under way; it is not offered as a substitute. It differs from the technique of exclusive use of fog from the exterior, in that the fire has been located, the building has been vented, thus minimizing the possi-

bility of back-draft explosion, and the openings for fog injection have been located with definite knowledge that the fog will be applied where it can be effective and not be nullified by interfering walls, partitions, etc.

The use of applicators as recommended (through subdividing walls) may very well prove to be a worthwhile alternative to the continuous use of master streams at exterior operations. If the fog can be applied effectively, the need for heavy streams may be reduced more quickly.

Fog from applicators can also be used with good results on fires involving cocklofts, voids, unventable rooms, ducts, and chimneys. Low-velocity fog from applicators is recommended for fires in occupancies that contain radioactive materials. Fog applied from applicators has successfully extinguished fires in the lining of chimneys serving large oil-burning systems in tall buildings. The fog can be injected through the lowest-level access opening located between the heating unit and the chimney, which is ordinarily intended for inspection and maintenance. This method is much more effective and far less hazardous than trying to force water down through the top of a chimney, some of which rise 20 ft above the roof and are located uncomfortably close to the edge. Trying to operate a nozzle from a ladder, particularly on a cold and windy night, is very dangerous, and in this situation it should be avoided. For this technique to be effective, however, there must be sufficient heat to vaporize and expand the injected fog. Such heat will rise and induce an upward draft. In some cases, it may be advisable to keep the heating unit working to ensure adequate heat and a favorable draft.

Fog applied by applicators centered over a tank is recommended for tank fires whose entire surface can be covered by fog. The size of the tank fire that can be successfully handled in this way is necessarily limited.

Fog can be applied from applicators to cover firefighters operating a solid stream through openings such as fire doors. In some cases, it will enable men to advance the solid stream so that they command a sweep of 180° through the door rather than the 40° or 50° possible without the help of protective fog.

Fog, upon being vaporized to steam, exerts a powerful smothering effect, which appears to be the primary factor in extinguishing fires in some flammable liquids such as gasoline, kerosene, and ethyl alcohol, as indicated by comparatively recent research. This smothering effect is also a factor in extinguishing or greatly retarding flaming combustion in wood fires. The smothering effect supplements the cooling effect realized when fog vaporizes to steam.

Disadvantages. Fog-line operators must keep in mind the temperature, volume, and pressure of the steam created so that ventilation can be effected to minimize the chances of injury. If the fire area is restricted in

size, an unlimited volume of steam, particularly when it is created quickly, may cause a ceiling or a window to give way.

Fog cannot be aimed as well as a solid stream. Whereas the latter can throw 75 per cent of the water within a 10-in. circle (or 90 per cent within a 15-in. circle) when it reaches the seat of the fire, much of the water from a fog stream will not reach the seat of the fire if turbulent currents have to be overcome. The paths of the light particles of the fog stream are readily changed by such currents or adverse winds, in both cases rendering the fog stream less effective. Fog is also diverted from its path by the tendency of the light particles to rise through accessible vertical channels, a tendency that makes fog less effective for flooding floors (a technique sometimes used at stubborn cellar fires).

Under ordinary conditions, fog lines do not have as good a vertical or horizontal range. This could be a disadvantage in extinguishment or in covering exposures. The difference in range exists because much more of the surface of the water in a fog line is exposed to friction, compared with a solid stream of the same volume. Fog streams do not have the impact of solid streams and are therefore less effective in venting windows from the exterior of the structure or in turning over material during the extinguishing or overhauling phases at fires such as demolition debris fires, where the questionable stability of the structure involved may make an exterior operation advisable.

The use of extremely high pressures has disadvantages as well as advantages. The danger of spreading grass or brush fires by applying high-pressure fog from the windward side has already been mentioned. Likewise, care must be exercised when such fog is used at structural fires; convection currents can be driven rapidly through the structure, possibly endangering fire personnel as well as the structure.

A serious disadvantage is that some firefighters do not realize that fog is no more a panacea than solid streams are. It is important to know how to use each kind of stream to maximum advantage. The officer who favors one technique for all fires has closed his mind to the possible alternatives. Fire officers should be familiar with all recognized techniques and should learn how to select and apply the most appropriate one.

Placement and Use of Fog Lines. In covering life hazard, extinguishing fires, and protecting exposures, the principles that govern solid streams are applied, with the limitations and peculiarities of fog always in mind. For example, where life hazard is present, the first line (fog or solid stream) must be placed to operate between the fire and the endangered occupants or between the fire and the means of escape. However, the possible effects on the occupants of the fog as it vaporizes to steam must be kept in mind.

When fog is used from the exterior of a structure, it would be very

unsound in many cases to close as many air intakes as possible, leaving only openings necessary for the insertion of nozzles. In all likelihood, the officer would not know the life hazard, the location and extent of the fire, the type and location of the vertical and/or horizontal channels by which the fire might spread, the material involved, or whether structural obstructions, such as partitions and walls, might prevent the favorable spread of steam and unvaporized water particles. In some cases, such obstructions could practically nullify the attack.

Obviously, the officer in command should know if there is a life hazard for occupants. If there is, an interior attack must be attempted, if at all possible. In an interior attack with fog, openings should be made, if necessary, in such a manner that the advancing units can drive the heat and smoke ahead and out of the structure. The officer should also know what is burning, since the material involved may prohibit the use of water.

Some persons maintain that the initial attack should be made within the area of major involvement while operating from the exterior through restricted openings. This is an impractical suggestion since the officer may not yet know the location and extent of the fire or the area of major involvement. Even if he did know the area of major involvement, structural obstacles might raise insurmountable difficulties.

It has also been suggested that the injection of water particles from the exterior should continue without interruption until the volume of condensing steam coming from the building has greatly decreased. Presumably, the application is to be within the area of major involvement. *The National Board of Fire Underwriters Bulletin* No. 166 has this to say: "The application of water to any mass of highly heated material even of wood, results in almost instantaneous liberation of a large volume of steam which is often mistaken for a hydrogen explosion. In a closed room or other confined space, this quick liberation of steam may blow out windows and even blow down walls. This is one reason why it is well to open windows and doors when attacking a hot fire." If water is applied in fog form, the explosive possibilities are maximal. Even if the explosive force is less than that described, it would at least be sufficient to break windows, making the selected nozzle positions dangerous and perhaps untenable. An explosion could also create a severe exposure hazard to other structures.

It has also been recommended by advocates of this technique that where large areas are involved in fire, and if sufficient openings are present during the attack, as much water as is readily available should be employed from the exterior of the fire building. It has also been suggested that a high concentration of heat within a closely confined space provides the most advantageous condition. This is all contrary to the re-

marks quoted above. This technique, if used as advocated, would be hazardous and impractical at a structural fire of some consequence.

Unquestionably, fog has great extinguishing powers when used in the right manner and place. However, the exclusive use of fog from the exterior of the fire building is not practical except in handmade cases. In addition to the reasons already stated, there is the possibility of a back-draft explosion when openings have to be made for the insertion of fog nozzles, perhaps necessitating the breaking of windows. The possibility of back draft should be anticipated and provided for in accord with a statement in the *National Board of Fire Underwriters Bulletin* No. 98: "For night fires and for all fires which give evidence that the building is well charged with smoke, it is well for the commanding officer to investigate before opening up the building for fire fighting. If the window panes are hot or the smoke which rises from the building rises rapidly, the officer can be assured that the only thing necessary to turn the interior of the building into an inferno is to provide more air. When this condition exists, extreme care is necessary in opening up the building and ample hose lines must be available for fire fighting. The opening of a door or window on the floor on which the fire is burning or on some lower floor, will probably result in a back draft explosion, etc." In many instances, particularly of the type just cited, it is preferable to use solid streams capable of greater reach, direction, and overall superiority where adverse winds have to be contended with. This does not exclude the use of fog. In a heavily involved building, a ladder-pipe fog stream may be just the thing.

Foam. Foam is applied primarily to extinguish fires in flammable liquids by blanketing the liquid surface, sealing off the flammable vapors from the air, insulating the liquid from the heat of the fire, and cooling the surface. Foam blankets are whitish in appearance. The fire service is familiar with two types of foam: chemical and mechanical. Chemical foam is produced by the reaction of carbon dioxide gas and a water solution containing a foaming ingredient. Mechanical foam is produced by mixing and agitating air with water that contains foam-making ingredients. Whether the bubbles contain inert gas or air is not significant for extinguishment. Ordinary foam, whether chemical or mechanical, is effective on hydrocarbons that are liquid at ordinary temperatures and pressures; but it cannot extinguish fires in liquefied gases. Special foams are usually required for alcohols and ketones and for the more volatile esters, as their solvent action tends to break down ordinary foam.

Foam must have lower density than the flammable liquid it is used on, so that it will float on the surface. It must also have low enough viscosity to spread or flow readily across liquid surfaces and around obstructions, and it must not break down rapidly under fire exposure or

when in contact with the flammable liquid; in addition, it must be long-lasting. Chemical foam is affected by the proportions of water and foam-making chemicals, by water and air temperatures, by the size and length of foam-delivery lines, and, in some cases, by water pressure. Mechanical foam is affected by the type of foam compound (hydrolyzed protein base or synthetic-foam fluid), by the proportions of water, foam fluid, and air, by thoroughness of mixing, by water pressure, and, to less extent, by water and air temperatures. Hard or salt water can be used to make mechanical foam but may adversely affect chemical foam. Wetting agents destroy most foams (see below, Wetting Agents).

There are three main kinds of foam-liquid concentrates: low-expansion, high-expansion, and alcohol-resistant. It is not essential to know the chemical ingredients of each, but one should know that the types should never be mixed and, of course, when, where, and how to use each kind. For example, in applying alcohol-resistant foam, if the time lag between diluting the concentration and forming the foam exceeds sixty seconds, there is danger that inferior foam will be produced. Some normally alcohol-resistant foams may be broken down if applied in such a manner as to cause submergence below the liquid surface.

The low-expansion protein-base type is more widely used for the protection of tank farms, aircraft crash fires, and hydrocarbon fires in general. This type of concentrate produces foams with expansion rates up to 10:1. High-expansion concentrates are more appropriate in areas where water supplies are limited. They are particularly effective for spill fires where rapid coverage is desired, and they have a high rate of expansion (16:1 to 20:1) and a high rate of flow and coverage because the foam is more fluid.

The quantity of foam required for extinguishment varies widely. For fires in small indoor tanks of flammable liquids, a few inches of foam may be sufficient as a cover: in large outdoor tanks, several feet of foam may be necessary. The necessary rate of application is affected by the method and by the characteristics of the flammable liquid. The recommended minimum rate of application for fixed systems is a water rate to the foam-producing equipment of $\frac{1}{10}$ gal of water (or combined solutions) per minute per square foot for delivery to the fire. For hose-stream operations, increased delivery rates are recommended.

Application. Mechanical-foam play pipes can deliver a straight stream or a spray or both. The effective range varies from 20 to 160 ft, depending upon pressure, capacity, and design. The capacity varies from 15 to 1,000 gal per minute water rate.

Some departments furnish their apparatus (it is ideal for apparatus with booster pump and hose) with 3 per cent low-expansion liquid in 5-gal cans. At an expansion rate of 10:1, 3 gal of this liquid plus 97 gal

of water will produce approximately 1,000 gal of air foam; 5 gal of liquid foam plus 160 gal of water will produce about 1,650 gal of foam. The liquid used is a solution of hydrolyzed proteinaceous material containing additives to control the viscosity, lower the freezing point (it is effective down to 0°F), prevent decomposition, and increase fire resistivity. Best nozzle pressures are 75 to 100 psi. Combination pick-up and air-aspirating nozzles have a 2-in. discharge opening with a swivel threaded to 1½-in. threads that are standard for some departments.

The nozzle is operated by immersing the end of the pick-up tube in the can of air-foam liquid and attaching the nozzle to any of the following:

1. A 1½-in. hose line, the most common and the most recommended procedure.

2. The 1-in. line off the booster reel, with the use of an appropriate adapter. If the five lengths of booster hose are used, the engine pressure should be at least 200 psi to guarantee the required minimum operating pressure of 60 psi at the water inlet of the nozzle.

3. Any larger line reduced to a 1½-in. fitting.

4. Directly to the barrel of a controlling nozzle whose extension piece and tip have been removed. In some cases, an adapter may first have to be placed on the barrel.

5. Any layout of hose that can be made up to the 1½-in. fitting and give the required pressure at the pick-up tube.

Considerable experimentation has been done on subsurface application of mechanical foam, with favorable results in many cases. In this method, foam is pumped into a tank below the surface through existing piping. Extinguishment is effected when the foam floats up and covers the surface.

Limitations. Foam streams are not suitable for use on film vaults and pyroxylin plastics or for similar hazards involving chemicals in which oxygen sufficient to sustain combustion is inherent. In general, foam should not be used on metal fires or on "live" electrical equipment (see below, Extinguishing Agents for Metal Fires).

If foam is applied to flammable liquids heated to 250°F or above, boilover may result unless the foam is discharged through special nozzles placed several feet above the liquid surface. Foam may be rendered ineffective by water discharged from hose streams or sprinklers.

Advantages of Mechanical Foam. The advantages of mechanical over chemical foam include the following:

1. The equipment required is less expensive and simpler to operate and can be placed in operation more quickly. It does not require the constant attention and the manpower necessitated by the use of generators. A chemical-foam hose line requires, in addition to the ordinary

equipment and apparatus, a generator with hopper attached and an adequate supply of foam powder. With $2\frac{1}{2}$-in. hose, the minimum size for chemical foam, an open $1\frac{3}{4}$-in. nozzle is used. When the generator gage registers 100 lb of flowing pressure, the foam powder is poured into the hopper. The discharge line from the generator to the nozzle should be limited to 100 ft for best results, and the powder must be stirred sufficiently to ensure proper settling.

2. The mechanical foam can be switched quickly to a plain water stream merely by removing the pick-up tube from the can of foam liquid.

3. It flows readily, flows around obstructions, does not obstruct itself, and achieves quick coverage, and therefore quick extinguishment.

4. Soft water, hard water, and air and water temperatures have less adverse effect on mechanical foam.

5. Methods of producing mechanical foam at fires are more numerous and more flexible than those for chemical foam. It can be applied premixed; at the end of the hose line with the pick-up tube and aspirating nozzle through various arrangements of hose, adapters, etc.; at any part of the hose line with a suction proportioner; and at the pumps with a suction proportioner.

6. Mechanical foam can be used with small-sized hose, whereas chemical foam requires larger sizes.

7. In addition to normal application, it can be applied as regular foam below the surface.

8. Vigorous agitation of an oil surface has less adverse effect on mechanical foam.

9. The foam blanket does not harden with time and therefore is comparatively easy and inexpensive to remove.

10. It can be used to extinguish secondary fires resulting from the use of tricresyl phosphate or boric acid in triethylene glycol as extinguishers on magnesium fires (see below, Extinguishing Agents for Metal Fires).

11. It requires less space for storage and transportation. A 5-gal can of liquid will produce about 1,650 gal of foam. An equivalent-sized can of chemical powder will ordinarily produce less than one-third as much foam.

Mechanical foam obviously possesses advantages in storage, transportation, and application (simplicity, speed, variety, and manpower needs) over chemical foam. However, some experienced fire officers feel that, in some cases, the chemical-foam blanket is a superior extinguishing agent. The final word has not been said on this point and cannot be until adequate research and experimentation has been done.

Wetting Agents. Wetting agents reduce the surface tension of hard or soft water from approximately 70 to 25 dynes (units of cohesion). Either salt or fresh water may be used with a wetting agent. The solution can

be applied premixed from fixed systems or from booster tanks, or it can be injected into a hose line at a selected place by means of a proportioner, which injects the amount of wetting agent properly proportional to the flow of water in the line.

Advantages. The advantages of using a wetting agent with water include the following:

1. Because of the greater penetrating qualities of the solution, less water will be used. Consequently, there will be less runoff and less property damage.

2. It can be used with fog. There is quicker conversion of fog to vapor, resulting in quicker absorption of heat and, consequently, quicker extinguishment. In this form, it is particularly effective on some class B fires involving high-flash-point products.

3. Wetting-agent solutions are effective on smoldering and hidden fires, as in baled cotton, paper, and rags; fires in sawdust or where charring might ordinarily repel water penetration; brush, grass, and duff fires; apartment fires in residential buildings, where the solution is particularly appropriate for fires in upholstered furniture (it has been estimated that one-fifth to one-third the usual amount of water will suffice when a wetting-agent solution is used on such fires); class B fires, in which the solution is very effective in fog form, as the water has a tendency to froth or foam when surface tension is reduced, thus smothering the fires; and fires involving natural and foam rubber, coal, and paint. In general, wetting-agent solutions are effective against the same kinds of fires as water.

4. A wetting-agent solution has a definitely favorable effect on the overhauling phase of an operation, on preventing rekindles after the department has left the scene, on protecting exposures, and on reducing the life hazard to members. Less structural overhauling will be necessary, since the solution can penetrate charred structural members such as wooden floor beams. This reduces the extent to which a structure has to be opened up for examination. Overhauling of contents is reduced also, since baled cotton and paper, upholstered furniture, etc., will not have to be opened up for examination to the extent necessary if only plain water was used to extinguish the fire.

The likelihood of a fire being rekindled after the fire department leaves the scene is lessened when a wetting-agent solution has been used because of its great penetrating powers and more permeating extinguishing effect. Thus, it is more likely to extinguish hidden fires that might escape the notice of a fire officer.

A wetting-agent solution provides better protection than plain water for exposures endangered by radiated heat, because the structure will absorb more of the solution than of water alone. Consequently, a greater

amount of radiated heat is needed to dry out and ignite a frame structure that has been saturated by a wetting-agent solution.

These solutions reduce the life hazard to the firefighters by lessening the toxicity of the smoke. The reduced surface tension of the solution, especially when used as a fog, causes increased absorption of the smoke particles in suspension.

5. A final advantage is that, because fires can be extinguished more rapidly and thoroughly with wetting-agent solutions, fire companies can return to quarters more quickly. This means better overall fire protection for the community.

Disadvantages. Among the disadvantages of using wetting agents with water are the following:

1. Some types of wetting agents are corrosive, necessitating the use of inhibitors. However, a wetting-agent solution that meets NFPA standards is no more corosive than plain water to steel, brass, bronze, and copper. Some types may not be corrosive, but they are detergents and accelerate corrosion.

2. The wetting agent may increase the electrical conductivity of the stream.

3. A wetting-agent solution cannot be used to produce a good foam stream. Recently, however, insulating air-water foam (containing small amounts of wetting agents) has been developed. It can be used as an insulating and reflecting thermal barrier for large surfaces exposed to radiant heat or direct flame. This type of bubble protection is referred to as *fluid insulation.*

4. The range and pattern of fog streams are adversely affected, and the reduced surface tension tends to affect the range of solid streams adversely. Wetting agents that meet NFPA standards, however, will not appreciably change the range and discharge capacity of solid streams or spray nozzles, and the discharge angle of spray nozzles will not be changed by more than 10 per cent.

5. Wetting agents are not advisable in soda-acid and antifreeze extinguishers, which depend on a balanced chemical reaction for operation.

6. The effectiveness of salvage or protective covers susceptible to the penetrating qualities of a wetting-agent solution is reduced.

7. The use of wet water to extinguish fires involving flammable liquids and greases is limited to materials insoluble in water, such as petroleum products of the high-flash-point type. On water-soluble materials of the alcohol type, some control may be effected, but extinguishment is questionable.

Conclusions. Obviously, the advantages far outweigh the disadvantages. Such solutions make a little water go a long way and therefore

are strongly recommended for areas where water supplies are limited. They are recommended for use in fabric-industry occupancies, since wetting agents are very appropriate for fires in fabrics. They penetrate to extinguish hidden fire but do not injure the fabrics, and they minimize overhauling of the contents.

Other Extinguishing Agents

Chemical Powder. The extinguishing power of dry chemical powder (such as sodium or potassium bicarbonate) was first thought to derive from sweeping the flame from the surface of the burning liquid in class B fires. Later, the mechanism was thought to be the endothermal conversion of sodium bicarbonate to sodium carbonate, water vapor, and carbon dioxide, thereby causing a cooling action and evolving inert gases at the point where oxidation of the fuel could be stopped more effectively. A more recent explanation is that dry chemical powder extinguishes primarily by chemical chain-reaction interruption. Effects of cooling or dilution of reactants, so important in other extinguishers, are deemed to be relatively minor in the case of dry chemical.

The chemical chain reaction, which is thought to be essential to the existence of fire, requires the presence of free radicals in the flame zone. These interact with both fuel and oxygen to produce a continuing or increasing supply of more free radicals, and thus the flame reaction proceeds in real chain fashion. The free radicals are self-propagating unless captured by condensing on, or interacting with, some substance that renders them inert. The fine particles of chemical powder, when introduced to the flame area, apparently capture enough of the free radicals to interrupt the chain reaction and thereby suppress the flame nearly instantly.

Potassium bicarbonate, more commonly known as Purple K powder, is also being experimented with as a dry-chemical extinguishing agent. It is said to have greater extinguishing possibilities than sodium bicarbonate.

Trucks designed to carry several tons of chemical powder have turret nozzles that discharge 25 lb of powder per second with a range of 90 ft.

Carbon Dioxide. In carbon dioxide fire extinguishers, the liquid contents are under high pressure (800 to 900 psi at normal room temperature). Low-pressure carbon dioxide is also available. By means of a refrigerating unit, carbon dioxide may be cooled to 0°F, at which temperature it can be compressed at 300 psi. Refrigeration is maintained continuously; should it fail, the temperature and pressure would rise naturally but comparatively slowly, so that pressures at which relief valves harmlessly discharge the carbon dioxide are not reached for as

long as twenty-four hours. Because of the lower compressing pressure, containers of considerably less bulk and strength can be used to store the carbon dioxide, making it possible and practical to provide large quantities on mobile equipment. Equipment carrying five and more tons of carbon dioxide is thereby made available for fire protection at airfields in anticipation of airplane fires. This kind of protection is also practical for aircraft carriers, engine compartments, machinery spaces, cargo holds on vessels carrying both dry and liquid flammable cargo, and similar places where the carbon dioxide could extinguish fires without causing the damage that water might.

Carbon dioxide should not be used on fires involving cellulose nitrate film vaults and other pyroxylin plastics or chemicals that can release sufficient oxygen to sustain combustion. Fires in oil-storage tanks with a surface area of more than 250 sq ft are not usually fought with carbon dioxide, although this agent has been used effectively to extinguish fires at vents and other openings in the tops of large oil tanks.

Carbon dioxide is more effective if applied before the fire has been burning long enough to heat objects to the point where there is danger of reignition. Therefore, quick-operating controls are recommended for fixed systems; in addition, manual control should always be provided.

Halogenated Hydrocarbons. These agents are composed of carbon, hydrogen, and a halogen (fluorine, chlorine, bromine, or iodine). They can interrupt the chain of combustion and, being nonconductive, can be used effectively on many class B and C fires.

Older, and possibly better known, halogenated hydrocarbons are carbon tetrachloride, chlorobromomethane, and methyl bromide.

During World War II, the Germans carried out tests on chlorobromomethane and were considering its use as an extinguishing agent in military aircraft. Some extinguishers containing this agent have been approved for class B and C fires. When released at fires, chlorobromomethane decomposes and produces traces of hydrochloric acid and hydrobromic acid. Therefore, the same precautions should be taken that are recommended for extinguishers with a carbon tetrachloride base. Chlorobromomethane is easier to handle than methyl bromide because it is liquid at ordinary temperatures; it is considered to have about equal extinguishing efficiency at proper discharge rates and pressures. The boiling point of chlorobromomethane is about 153°F, vapor density is 4.48 (air = 1), specific gravity of the liquid is 1.93 at 68°F, and freezing point is −124°F. Ignition temperature is 1020°F, but with proper use, ignition should not occur. However, the use and application of this agent should be engineered to avoid the potential danger.

Dry chlorobromomethane is corrosive to aluminum, magnesium, and zinc but practically noncorrosive to steel, brass, and lead. Control over

moisture content is important (not above 0.02 per cent), because in the presence of moisture it will corrode iron.

Methyl bromide, a brominated hydrocarbon, can be used successfully on class B and C fires. It has not been recommended or approved for use mainly because of its toxicity. Enclosed spaces into which methyl bromide has been discharged should be thoroughly ventilated before anyone enters. The harmful effects from exposure to this agent are not always instantaneous; they are insidious, attacking the sensitive tissues of the respiratory system.

Methyl bromide is an effective extinguishing agent because of its high vapor density (3.27) and low boiling point (40°F). Because of the low boiling point, however, it is difficult to handle at normal temperatures and pressures. It has an ignition point of 998°F but is only weakly flammable within a 1 per cent range of concentration (13.5 to 14.5 per cent by volume in the air). This degree of fire hazard is not ordinarily significant, but care should be exercised.

More recent developments and research reveal additional and apparently more effective and less toxic extinguishing agents among the halogenated hydrocarbons.

Table 3-1

Chemical name	Chemical formula	Halon designation*	Reported relative effectiveness, %
Bromotrifluoromethane..........	$CBrF_3$	1301	100
Dibromodifluoromethane........	CBr_2F_2	1202	67
Dibromotetrafluoroethane.......	$CBrF_2$–$CBrF_2$	2402	57
Bromochlorodifluoromethane.....	$CBrClF_2$	1211	46

* The Halon designation specifies in succession the number of atoms of carbon, fluorine, chlorine, bromine, and iodine. Terminal zero digits are not expressed.

Chlorobromomethane (CH_2BrCl), with a Halon designation of 1011, was given a relative effectiveness rating of 45; carbon tetrachloride, with a Halon designation of 104, was rated 34.

Halon 1301, top-ranking in this particular group, is stored and handled as a liquefied compressed gas. It has a boiling point of —72°F and a vapor pressure of about 200 psi at room temperature. In respect to these two physical properties, it falls between carbon dioxide and vaporizing-liquid agents (such as carbon tetrachloride); hence, it is more appropriately described as a liquefied compressed gas than as a vaporizing agent. The high efficiency, low toxicity, desirable chemical and physical properties, and freedom from corrosive effects of this agent have led to its adoption by major aircraft organizations as an aircraft-engine fire

extinguisher. Many American-made aircraft are protected by Halon 1301 against in-flight engine fires.

Where streams from extinguishers or hose lines are used, the physical characteristics of halogenated compounds as a group may limit their theoretical effectiveness. Final conclusions depend on further development of these agents in practical situations.

Extinguishing Agents for Metal Fires. A comparatively new agent for extinguishing metal fires is TMB, a colorless liquid boron compound containing a high percentage of trimethoxyboroxine. It has been found effective on magnesium (in both the molten and the solid state), titanium, and zirconium and has also been used to control the burning of sodium and sodium-potassium alloy. TMB is a flammable liquid with a flash point of 59°F; it burns quietly with a low green flame. It should be stored at temperatures above 32°F, as its viscosity increases greatly at lower temperatures. TMB is effective in knocking out the brilliant hot white flame (over 5000°F) of a magnesium fire by the combined effort of quenching the white fire and providing a burning boric oxide coating over which water is sprayed to produce the necessary cooling for complete extinguishment. It is used in 2½-gal pressurized extinguishers, identified by a 6-in. band of fluorescent orange paint around the top of the unit.

Other extinguishing agents for magnesium fires are a solution of 9 to 17 per cent boric acid in triethylene glycol and tricresyl phosphate. Both these agents produce a secondary fire that can be controlled with water fog or mechanical foam. Boron trichloride gas has proved to be suitable against magnesium fires in heat-treating ovens, but it is very irritating to respiratory tissues. Boron trifluoride gas is also irritating, though effective in concentrations as low as 0.04 per cent. Boron trichloride requires about ten times the concentration of boron trifluoride.

G-1 and certain dry powders will also extinguish metal fires. G-1 is composed of graded granular graphite, to which are added phosphorus-containing compounds to improve extinguishing effectiveness. Heat causes these compounds to generate blanketing vapors, which exclude air from the burning metal. The graphite, by conduction, cools the metal below its ignition point. G-1 must be applied with a shovel or hand scoop; it cannot be discharged from an extinguisher. It is suitable against fires in dry or oily magnesium chips, uranium, titanium turnings, zirconium chips and turnings coated with an oil-water coolant (fires involving moist zirconium chips are only controlled, however, not extinguished), sodium, potassium, sodium-potassium alloys, and lithium.

One dry-powder extinguishant has a sodium chloride base with additives to facilitate free flow and heat-caking, which forms a crust that excludes the air and extinguishes the fire. Such an agent can be used

against the same fires as G-1, except lithium fires in depth; it can be used for lithium spill fires, however.

Metal fires are considered further in Chap. 7.

Inhibitors. Substances that accelerate the speed of a chemical change without actually taking part in the process are catalysts. Negative catalysts, which retard the speed of reaction, are inhibitors. The mechanism involved is not too well understood at present, but catalysts definitely exert enormous influence on chemical reactions, including, of course, the process of combustion.

PART 2

Ascertaining the Problems and the Order of Solution, or Sizing Up the Situation

4

The Approach

Every fire presents different problems to the fire service. Yet at each fire, the commanding officer must make decisions about what the problems are and the order of their solution. Part 2 is designed to show how the same mental approach can be used at all types of fires to assist in decision making. This approach, designed to systematize sizing up the situation, consists essentially of the following three steps:

1. Decide upon the *objectives* (major problems).
2. Decide upon the *activities* (the derivative or work problems) essential to achieve the objectives.
3. Note the presence of *pertinent factors* and evaluate their effect on the essential activities.

The approach suggested calls for a knowledge of cause and effect relationships among objectives, activities, and pertinent factors. Such knowledge will enable the commanding officer to recognize his work problems and the order of their solution. Part 3 deals with the solution of existing problems.

Of course, pertinent factors will affect both major and derivative problems, but if the latter are handled properly, the former are taken care of automatically. Hence, except when rescue is the major problem, pertinent factors are discussed as they affect derivative rather than major problems. The distinction between objectives, essential activities, and pertinent factors should be clearly understood.

Objectives, or major problems, are threefold:

1. To rescue occupants. This objective has number one priority.

2. To extinguish the fire by a direct attack when possible and feasible, bearing in mind that confinement of the fire is a necessary concomitant. This is the objective when there is no life hazard for occupants or after occupants have been removed. In some cases, the commanding officer may have to abandon this objective temporarily (e.g., change from an interior to an exterior attack) because of unfavorable developments.

3. To confine, control, and then extinguish the fire. This may be the objective when required rescue work has been done and when quick and complete extinguishment is temporarily impossible.

It is extremely important that all officers working at the fire know what the objective is, since it influences the risks to which personnel should be subjected. If the objective is rescue, greater risks are warranted.

The next step is to determine what activities are essential to achieve the objective. For proper determination, the officer must know what activities are associated with the attainment of each objective.

Activities associated with rescue may include locating the fire, trying to determine its extent, getting information about the location and condition of the trapped occupants, forcing entry, ventilating to assist rescue work, searching for and removing occupants, placing and using hose lines, rendering first aid, and obtaining medical aid as necessary.

Activities associated with extinguishment may include locating the fire, trying to ascertain its extent, selecting the extinguishing agent (it may not be water), forcing entry, placing and using lines, ventilating, checking for extension of fire, overhauling, and salvage.

Activities associated with confining, controlling, and extinguishing the fire may include locating the fire, determining its extent, deciding upon the order in which exposures should be protected, using the best means available (sprinklers, standpipes, master streams, fixed systems, etc.) to cover the exposures, selecting the proper extinguishing agent (it may be an oil fire), changing from a defensive to an offensive operation, forcing necessary entry, ventilating, overhauling, and salvage.

Other activities that could be associated with any of the specified objectives include assuming command, establishing field headquarters, establishing communications, calling for necessary help (fire service or other), supervising personnel, and coordinating activities (Chap. 15).

The third step in the approach is to note the pertinent factors present and to evaluate their effects on the necessary activities. This evaluation is considered in the next chapter. First, however, classes of fires are discussed, since decisions about fire operations are greatly influenced by the class of fire encountered.

Classes of Fires

There are four classes of fires: A, B, C, and D. Class A fires are considered almost exclusively in succeeding chapters and hence are mentioned only briefly at this point. They are fires in ordinary combustible materials, such as wood, paper, and cloth. Since fires of this class are chemically the simplest, the most effective extinguishing agent is water; the cooling and quenching effects of water or water solutions reduce the temperature of the burning material below its ignition point.

Class B fires are those in flammable petroleum products or other flammable liquids, greases, etc. The blanketing-smothering effect of oxygen-excluding media is a very effective means of extinguishment. Fog streams extinguish fires in kerosene, fuel oil, linseed oil, lubricating oil, and other heavy viscous liquids. The fire will be extinguished if water spray completely covers the surface of the material and cools it below the temperature at which it will give off sufficient vapor to support combustion. This is not an effective method with liquids having flash points below the temperature of the water spray. If sufficient steam can be generated by the heat of the fire when fog is applied, oxygen will be displaced or excluded and a favorable smothering effect will result.

An emulsion that will not burn can be created on the surface of burning oils or similar flammable materials with which water will not mix. The emulsion results when water spray strikes the burning surface. This method is more effective with more viscous liquids: the emulsification persists for a longer time in such cases, thereby minimizing the danger of flashback.

If flammable materials are soluble in water, the fire may be extinguished by diluting the burning substance. The dilution necessary for extinguishment, and consequently the volume of water and the time required, vary greatly. Fires in liquids heavier than water, such as carbon disulfide, can be extinguished by flowing water gently onto the surface from an open butt, thereby floating the water and smothering the fire.

"Wet water," not less than 2 per cent by volume, will extinguish fires and prevent boilovers in hot asphalt, oil, tar, and products that foam when heated.

Class B fires can also be extinguished by vaporizing liquids, carbon dioxide, dry chemical, and foam (Chaps. 2 and 3).

Tests under controlled conditions indicate that fires in oils that have flash points above their storage temperatures can be extinguished or controlled by air introduced under pressure at the bottom of the tank. The surface of the burning liquid is cooled to the main body temperature by the injection of air into the lower area, which agitates the oil in

the tank and pushes the cooler oil in waves to the surface. Hot-oil layers are reduced by this method, thus lessening the danger and severity of slopovers during fire operations. The injection (air) pressure is determined by the static head to be overcome (1 psi per 2½ ft, approximately). The optimum air flow is affected by the diameter of the tank involved. If the main body temperature can be reduced below the flash point of the fuel, the fire will be completely extinguished. If the temperature is reduced but still remains above the flash point, the fire will continue to burn but at a reduced rate. The fire can then be more readily extinguished by other means. A flammable liquid can continue to burn only so long as the vapors above it form a combustible or explosive mixture with air. The ability of a liquid to form vapor increases with its vapor pressure, which, in turn, increases with temperature. When the surface of a burning liquid is cooled, vapor pressure and rate of vaporization are consequently reduced. If they are reduced to the point where the vapor concentration goes below the lean flammability limit, the fire will go out.

The air-agitation method is not effective on extremely volatile liquids such as natural gasoline, nor is it recommended for liquids more volatile than winter-grade gasoline (13 lb Reid vapor pressure, which is calculated on the basis of the specific oil at 100°F). The potential of the air-agitation method has been recognized, but its use has been limited. It is not now recommended as a substitute for standard extinguishing methods.

The temperature of the contents of involved or exposed tanks may be kept below the ignition point by streams played on the exterior surface.

Boilover sometimes occurs with class B fires in large tanks. Boilover is an almost explosive ejection of the tank contents, which must have been burning for some hours. For boilover to occur, the involved liquid must contain petroleum fractions of widely different gravities and boiling points, such as may be present in crude oils and certain somewhat viscous oils that contain water. The lighter fractions of the crude oil burn off at the surface, leaving heated heavy fractions that sink, carrying the heat down. When sufficient heat reaches the bottom of the tank, where there is usually some water, the water boils and ejects the frothing contents violently. Gasoline and other refined petroleum products and flammable-liquid solvents are not subject to boilover.

Such boilovers can be anticipated, if not prevented, and proper precautions can be taken. The descending heat wave takes several hours to develop, and the rate of descent for various oils is known; therefore, the approximate time of boilover can be determined. In some cases, a paint indicator will reveal the level of the descending heat wave. Flames may heighten and brighten just before the boilover.

Slopovers are another possibility at oil-tank fires. These are overflows that may occur before the descending heat wave reaches the bottom of the tank. They can occur early if the tank has insufficient outage and if thermal expansion of the oil occurs early. They can also take place when violent boiling occurs on top of cooler oil, for example, if an attempt is made to precool the hot surface oil with water before applying foam. Violent boiling on the surface is also a possibility when foam is first applied to wet (more than 3 per cent water) fuel oils that have been burning for fifteen minutes or longer. Usually slopovers are small in extent, but they can have serious results.

Class C fires involve electrical equipment. The most important characteristic of the extinguishing agent selected should be its electrical nonconductivity. There are tables that list the distances at which it is safe to operate hose streams against specified voltage. For practical purposes, however, officers should depend not on memorizing such tables but on the fact that danger to firemen lies primarily in accidental physical contact with live wires or equipment or in stepping in pools of water that are electrically charged. There is little danger to firemen applying hose streams on wires of any voltage found in ordinary electrical distribution systems, provided that the stream is broken up before it hits the wire. There is little hazard in playing such streams on wires of less than 600 volts to ground from any distance likely to figure in ordinary firefighting. Electrical equipment should be approached carefully, if at all, during a fire, since there is the possibility of breakdown, which might result in abnormal voltage. Proper supervision by officers and assistance from persons familiar with the location and its electrical hazards are important.

At fires where electrical equipment is involved, the first step may be to deenergize the equipment. However, where underground street cables are involved, a public utility agency generally handles the fire in the cables. If help is asked from the fire department, it is, of course, promptly given. In most cases, the fire department merely checks for possible extension of fire into nearby structures via electrical connections from the street cables.

Total power shutdown may be inadvisable. Where practical and possible, service elevators and fire pumps for standpipe and sprinkler systems should be kept in service. Total power shutdown in a subway tunnel might extend the danger to many more trains than the fire train by leaving them stranded in the involved tunnel. In such situations, accurate information is essential for the fire officer and for the transit dispatcher. Portable communicating devices, such as sound-powered telephone and self-contained masks, may help in passing information as rapidly as possible (Chap. 13).

For efficient action against class C fires in tunnels, fire departments and transit or railroad authorities should work out effective procedures for shutting down and restoring power.

Class C fires can be fought with carbon dioxide, vaporizing liquids (carbon tetrachloride and chlorobromomethane, for example), and dry chemicals. Carbon dioxide extinguishers with metallic horns, however, cannot be used safely (Chap. 3). There is also a hazard in multipurpose nozzles, which may be accidentally switched from fog to solid stream, thereby increasing conductivity.

Class D fires involve combustible metals (Chaps. 3 and 7). Despite the profusion of information gleaned from research, much remains to be discovered about the specific sequence of physical and chemical steps involved in the burning of metals. Many metals such as uranium, plutonium, thorium, zirconium, magnesium, calcium, sodium, and potassium are subject to pyrophoricity and therefore tend to ignite spontaneously under conditions not well understood. Unlike flammable liquids, metals are inconsistent as to ignition temperatures when heated in air. For example, uranium in fine powder form can ignite spontaneously at room temperature, but in massive form it will not normally ignite even when heated to its melting point. Other factors affecting the pyrophoricity of metals are surface oxides, stress, moisture, and contaminants. The complexity of metal fires becomes obvious.

Experimentation has revealed that free burning of metals in air occurs at temperatures well above the melting point. For example, temperatures of over 5000°F are developed during combustion of magnesium, which has a melting point of about 1200°F. Well above the melting point, the metal vapor pressure is well within a range comparable with that of flammable liquids undergoing combustion. This suggests a close analogy between the mechanisms of combustion involving flammable liquids and flammable metals.

Current research related to metal fires is extensive, and revolutionary suggestions for handling them can be anticipated.

5

The Pertinent Factors

The pertinent factors that affect objectives at fires as well as essential activities include the following:

1. Location of the fire.
2. Extent.
3. Life hazard.
4. Time.
5. The presence of exposures and size of the exposure area.
6. Presence of auxiliary appliances in the fire building or in exposed buildings.
7. Water supply.
8. Street conditions.
9. Availability of help, a major factor necessitating mutual aid agreements in some areas.
10. Construction of the fire building and of exposed structures.
11. Occupancy of the fire building and of exposed structures.
12. Weather conditions.
13. Height.
14. Area.
15. Miscellaneous: Other factors can be classified as pertinent; for example, if simultaneous fires are in progress, the response of needed help will be adversely affected. The location of a fire in a remote, sparsely populated area could similarly delay the arrival of additional units.

During shipping strikes, piers may become more loaded with stored materials; in the event of fire, the use of hose lines will be impeded and overhauling will be more difficult.

In this chapter, the effects of the location of the fire, its extent, life hazard, time of occurrence, and exposure hazard are discussed, with emphasis on the more important effects.

Effects of Fire Location

Location affects the major problem of rescue as well as essential activities such as ventilating, checking for extension of fire, placing and using lines, and using special equipment. Obviously, it affects the entire fire operation.

Effects on Rescue Work. If the location of a fire cuts off the escape of endangered occupants, or hinders it by heat or smoke, a rescue problem exists. The problem is more difficult if escape is blocked by both heat and smoke and less acute when smoke alone intervenes. At any rate, the fire officer cannot evaluate the rescue problem until he has located the fire. When the fire is located, the officer can then determine where and how occupants are trapped, the severity of the conditions to which they are exposed, and the best way to achieve rescue.

Serious but not always dangerous smoke conditions can be caused on top floors of fireproof structures, even ten floors above the fire, if it is located near elevator shafts. These conditions require prompt attention lest the occupants of these floors overestimate their danger, particularly at night, and become panic-stricken. The smoke condition can be quickly alleviated by adequate ventilation, and panic can be averted by assuring occupants that they are not in danger.

In unusual cases, the location of the fire produces a severe life hazard and rescue work must be started before the fire is definitely located, for example, at subway fires. To contend with possible panic, the commanding officer may have to commit all available manpower to rescue work, waiting to locate and extinguish the fire until more units arrive.

Effects on Locating the Fire. Locating the fire is an essential activity in every case, and some fires entail long arduous operations because the fire is very difficult to locate. Usually, such fires are relatively inaccessible to attack, for example, fires in pier substructures, subcellars, and concealed spaces.

Effects on Ventilation. The location of the fire affects *where* to vent since one of the main objectives of ventilation is to localize the fire by minimizing its tendency to spread horizontally within the structure; generally speaking, this is achieved by opening up as directly over the fire as possible and feasible. This is of special importance when a fire is

extending into a cockloft via pipe recesses or similar channels. Opening up the roof in the wrong place may turn a first-alarm into a major-alarm fire. If the fire has cut off the escape of occupants, the building should be ventilated to draw off the heat and smoke regardless of where openings essential to rescue have to be made or whether such openings increase the intensity of the fire and possibilities of spread (not to occupied areas, of course). If horizontal ventilation only is required, the location of the fire will indicate the floor to be vented and the openings to be used.

The location of the fire affects *when* to vent if it creates a life hazard. In such a case, ventilation may have to be started as soon as possible even if hose lines are not ready or if an exposure hazard may be created or intensified.

The location of the fire can affect *how* to vent. For example, fires below ground level may have to be vented by opening sidewalk deadlights or by using fog streams, fires in stairways by opening the roof bulkhead, fires in windowless buildings by utilizing the air-conditioning system, etc. Where, when, and how to vent is discussed in Chap. 11.

Effects on Checking for Fire Extension. A fire located near a vertical or horizontal channel will spread readily by such means. A large fire will spread even more. The degree of exposure hazard within the fire building or to other buildings can be evaluated accordingly. The location of a fire may enable it to enter air-conditioning systems through inlets in exterior walls. All these facts concerning fire location influence the manner in which extension is checked.

Effects on Placement and Use of Hose Lines. If the location of the fire has created a life hazard, lines should be placed to facilitate rescue work and should be operated as soon as possible and until rescue is completed. If there is no life hazard, the fire location will still govern the placement of lines (Chap. 10).

Effects on Use of Special Equipment. A fire located at a high level may require the use of standpipe systems. Perforated-pipe systems may be needed if the fire is located in a cellar or subcellar. The fire location may also influence the decision to use sprinkler systems, cellar pipes, or fixed systems of various types.

Overall Effects. Getting fire operations under way in the most efficient and effective manner depends upon accurate information about the location of the fire. Unfortunately, operations are occasionally begun with a mistaken idea of the fire location. This only means delay, and it may increase the life hazard and make rescue work more complicated and extinguishment more difficult. The fire officer who quickly and accurately determines the location of the fire is best able to make proper decisions because he can more clearly define the problems that the fire presents.

Effects of Extent of the Fire

Generally, determining the location of a fire will produce some information about its extent. To the fire service, "extent of the fire" means its extent at the time the fire department arrives plus any subsequent extension. A fire of moderate extent on arrival of the fire service may sometimes become much larger if a length of hose bursts, if water supply is inadequate, or if the need for rescue work entails venting in a manner unfavorable to control and extinguishment. The extent of the fire may vary during a fire operation.

Determination of Extent. In some structural fires, it is extremely difficult or even impossible for officers, regardless of their experience, to determine accurately the extent of the fire in its early stages. Excessive heat and smoke, poor visibility, the need to cover a life hazard, the existence of numerous concealed channels by which the fire can extend, etc., may make determination difficult. The areas of heavy involvement may be known, but the exact extent often cannot be ascertained until all channels of spread and all exposed areas have been checked. Actually, when the exact extent of the fire is known, it is quite likely that extension has ceased and that confinement and control are imminent. However, officers in command should be reasonably conservative in reporting on fire extent. Premature reports that a fire is under control are frequently attended with disastrous consequences.

Effects on Forcible Entry. A light haze of smoke visible through expensive heavy glass doors that feel cool to the touch usually indicates fire of small extent; in such circumstances, entry should be forced in the manner least damaging to property. Where the extent of the fire is great, such consideration is neither expected nor warranted; speed in getting an efficient fire operation under way is more important.

Effects on Ventilation. The extent of the fire should have a reasonable relationship to the amount of structural damage done in ventilating. A hole should not be made in the roof when opening top-floor windows is sufficient. On the other hand, if the extent of the fire is great, proper ventilation is more important than structural damage.

Fire extent may determine whether roof ventilation should be attempted at all. If two or more floors in an old loft building are fully involved in fire, for example, attempts to work on the roof or in the structure are inadvisable unless necessary rescue work makes it imperative. If the fire extent is so great that roof or fire-escape venting is out of the question, heavy streams or the tips of aerial ladders can be used to break windows.

Other Effects. The extent of the fire will affect the amount and kind of overhauling needed (Chap. 11) and the nozzle type, size, and pres-

sure, the hose size, the number of lines, and the kind of operation (interior or exterior). More extensive fires naturally develop higher temperatures and consequently give off more heat by means of radiation, convection, conduction, sparks, and flying embers; thus, the hazard to exposed buildings is greater with fires of greater extent.

Effects of Life Hazard

When a life hazard is present, the first objective is rescue. The essential activities connected with rescue work are listed in Chap. 4.

Effects on Sizing Up the Situation. Fire operations must be set up to contend with the life hazard first and foremost. Rescue work takes time and may require the efforts of many, and perhaps all, of the units on hand. Ventilation unfavorable to controlling and extinguishing the fire may be needed to alleviate the life hazard. Therefore, the fire may spread unpredictably while the rescue operation is in progress. It is more difficult for the commanding officer to size up a fire whose location and extent may be rapidly changing. Transmitting additional alarms is only a part of the solution, since the officer must still be able to assign incoming units most effectively.

When a life hazard exists, the response of the fire service is frequently greater than the extent of the fire ordinarily warrants. Operations to extinguish or to confine, control, and extinguish the fire may be delayed to cover the life hazard, resulting in a fire that is larger and more difficult to attack than that first reported. As a precaution, before such possibilities become actualities, the commanding officer may transmit an additional alarm or call for special equipment, rescue or squad companies, ambulances, and perhaps public utility units.

The decision to cover the life hazard first can, of course, be made readily. But decisions must then be made about the best way to rescue occupants. The possible problems of fire extension and the definite problems of confinement, control, and extinguishment require solution, but where a life hazard is present, decisions about such problems naturally become more difficult.

Effects on Rescue Work. In rescue operations time is usually short. Forcible entry is made with less regard for structural damage, exposure hazards, or the availability of a hose stream to protect fire personnel. As many hose streams as are necessary to cover the life hazard are stretched and operated at once (Chap. 10). An aerial ladder truck equipped with ladder pipes is first used, if needed, to effect rescues via the aerial before the ladder pipes are put to work to extinguish the fire. The quad with its manifold potentials is used in the way that best solves the rescue problem under the circumstances, taking into account the presence or absence of

other apparatus. In any event, rescue is the number one problem. Rescue work is affected by the location and extent of the fire, construction of the fire building, the number of people trapped, their mental or physical condition, achievement of helpful ventilation, availability of protecting hose streams, and accessibility of occupants via ladders, snorkels, roof ropes, etc. Panic, bad weather conditions, poor visibility due to smoke, heat, etc., make the life hazard more severe and hence make rescue work more difficult.

Effects on Covering Exposures. Covering exposures can readily become more difficult when there is a life hazard. The obligation to concentrate on the life hazard may delay the attack on the fire itself. The fire may grow, creating new exposure hazards and intensifying those already present, both internally to the fire building and externally to other structures.

Effects on Supervision of Fire Personnel. In accord with the highest tradition of the fire service, graver risks are taken by officers and men engaged in rescue work, thus increasing the life hazard to firefighters. The life hazard should be covered with the greatest possible efficiency primarily to effect the rescue and secondarily to effect it without unnecessarily jeopardizing fire personnel. This entails proper ventilation, stretching and operation of lines, and use of masks, ladders, and other equipment associated with life-saving operations. The highest quality of supervision by officers is necessary to ensure that equipment is used properly and that men are relieved as circumstances require and permit. If rescue work is not handled efficiently and effectively, the officer in command can expect that the remaining problems will assume uncalled-for proportions.

Effects of Time

Time affects every fire operation. The time of occurrence may create both advantages and disadvantages for the fire service.

Night Fires. It may be more difficult to size up a fire at night because of poor visibility. Often at night fires are not discovered as quickly as during the day; there may be delay in turning in the alarm. The life hazard is greater in residential buildings but less in shops and business structures. Because of darkness visual observation is impaired, communication may be more difficult, and operations are consequently slowed down.

Although life hazard is less in business structures at night, the problem of forced entry is more complicated. Fire may burn in closed and deserted buildings for a long time before it is discovered.

Rescue work is made more difficult at night, since residential build-

ings are more crowded and since persons waking up to cries of "fire" are more prone to panic than those who confront a fire wide awake. Some occupants may be old and infirm and others too young to help themselves. The search for, and removal of, occupants is also hindered by poor visibility.

As a rule, night fires require more hose streams for extinguishment, since they have generally been burning longer. Traffic is less heavy, however, and is less apt to interfere with obtaining hydrants and with the stretching and use of lines. Night fires are generally more extensive, with greater possibilities of spreading, by the time the fire department arrives. Consequently, overhauling of both structure and contents will be more extensive than at day fires (there is a rather direct relationship between the extent of the fire and the extent of overhauling). Overhauling at night is more dangerous to fire personnel because poor visibility increases the chance of injury. Statistics indicate that a surprisingly large percentage of injuries occur during overhauling and that many happen at night fires. Overhauling at night should be done with stringent precautions, such as providing adequate lighting and carefully checking on dangerous conditions. Precautions are taken at fires in the daytime also, of course, but they are particularly important at night.

Although it cannot be statistically proved, it seems reasonable to assume that more apparatus is required at night fires: night fires are generally more extensive, their potential for spread is greater, and a life hazard at night creates more severe problems than in the daytime. Additional alarms are more often transmitted under these circumstances. Some departments have special searchlight apparatus that responds only at night. Officers should always be aware of the benefits of placing ordinary apparatus so that its searchlight equipment can be used. The basic consideration in positioning apparatus, however, is to achieve the unit's major objective in operating at the fire.

Pressure in public water mains is generally better at night because of the reduction in demand. However, an officer in command of the only piece of apparatus with pumping equipment responding in suburban areas where hydrants are few or nonexistent can certainly be confronted with perplexing problems involving time and the use of the available water supply. How soon can he expect help in the form of a water-supply truck or other apparatus with pumping equipment? In the meanwhile, how can he best use his immediately available water supply (for example, in the booster tank)? Will a booster line be effective for the job? If not, what procedure is to be followed? Only one answer is certain: where a life hazard is present and only booster-tank water is available, the booster line or lines should be stretched and operated as soon as possible between the fire and the occupants, regardless of whether or

not the fire can be put out. Units of this type should be provided with at least two modern heat-resistant suits, since members may have to endure abnormally high temperatures during rescue work without the protection of adequate hose streams.

Daytime Fires. Daytime fires are usually reported earlier than fires at night, and the fire service has the great advantage of daylight visibility. Consequently, fires are easier to size up, and communication is more readily maintained during operations. Life hazard in residential buildings is usually less than at night, but in business or public structures it may be greater. Public structures are usually open during the day, however, facilitating access to the fire.

Since daytime fires are apt to be reported earlier, fewer hose lines may be needed. However, daytime traffic sometimes obstructs water supply from hydrants and makes it more difficult to stretch and operate lines. The danger to exposures can be assessed more rapidly and accurately in daylight, but the fire may spread more rapidly since more windows are open as a rule, especially in hot weather. It seems likely, however, that less equipment will be needed to fight the same fire in daytime than at night, for reasons given in the preceding section.

Other Effects of Time. A congested traffic situation, such as on holidays and weekends or during business hours, will slow down response of the fire service as well as operations at the scene. A fire in a car on a congested highway can present a problem out of all proportion to the extent of the fire. Procedures for such fires should be preplanned as much as possible. A booster-equipped apparatus responding against traffic will suffice in some instances.

Seasonal conditions, such as develop during the Christmas season, can affect fire operations because stores are more crowded, thus increasing the life hazard; large amounts of stock are on hand, increasing the rubbish-disposal hazard and the supply of fuel in the event of a fire; and Christmas trees in homes and elsewhere burn with great speed and spread fire rapidly.

The dry season affects the number and severity of brush and forest fires as well as the potential development of conflagrations, and so concerns the fire service.

Effects of Exposures

Where exposures are higher than the fire building, the hazard is more severe because of the natural rise of heated air and gases. The probability of extension to adjoining structures, even on the lee side, is less likely when exposures are lower than the fire location. The closer the exposure to the fire, the greater the hazard generally. Combustible con-

struction is naturally more susceptible to ignition than the fireproof type wherein exterior walls and openings are more fire-resistive.

Occupancies that, if involved, would present the worst problems should be given appropriate priority. The commanding officer must evaluate possible causes of extension (conduction, radiation, convection, sparks and embers, etc.) and anticipate when potentialities may become actualities so that required countermeasures can be taken in time. He must take into account direction and velocity of the wind, available equipment, available manpower, water supply, and all pertinent factors to determine how best to cover exposures.

Effects of Exterior Exposures on a Fire Operation. When such exposures have to be protected, the objective of the operation is to confine, control, and then extinguish the fire—with emphasis on "confine"; activities essential to achieving this objective are listed in Chap. 4.

How exposures are to be checked for fire extension and how they are to be protected in proper order under prevailing fire conditions is treated in Part 3.

6

Effects of Building Construction

It is important for the fire officer to know the type of structure that is burning; such knowledge will help him determine the rapidity with which the fire may spread, whether it will extend vertically or horizontally or both, and how the objectives of rescue and extinguishment can best be achieved.

Knowledge of construction is essential in order to operate efficiently at structural fires, which in many instances provide the consummate test of officers' knowledge and skill. Officers who more often succeed in checking internal extension of fire without, of course, unduly jeopardizing their subordinates should be rated more highly than those who resort more often to exterior operations, thereby causing maximum instead of minimum damage, and consequently more often "losing the building."

General Structural Features

Officers should be familiar with the following general features of construction: channels by which fires spread vertically and horizontally; structural features that bear on rescue work, ventilation, etc.; auxiliary firefighting equipment; height; area; and concealed spaces. Fire can spread vertically by means of partitions, stairways, elevator shafts, dumbwaiter shafts, ramps, escalators, pipe recesses, air and light shafts, ducts in air-conditioning systems, ducts serving large cooking ranges, conveyors, and other floor openings. It can spread by burning through

floors and can travel from floor to floor on the exterior of the building. Channels unprotected by fire-stopping or fire-resistive enclosures present the greatest hazard. Fireproof buildings generally have adequate protection for vertical channels.

Channels by which fire spreads horizontally include hallways, corridors, common cocklofts, ceiling spaces, inadequately protected door or window openings, and ducts. Fire can also travel horizontally when heat is conducted through intervening walls or partitions, or from beam to beam when they abut.

All structural features influence phases of a fire operation, but some features have special significance for certain phases. For example, fire escapes, stairways, etc., by which occupants may be reached are important to rescue work. The channels by which the fire can spread will influence ventilation. The location of stairways, hallways, and fire escapes may determine the placement of hose lines. In overhauling, knowledge of the structural layout enables the officer to open up the structure most effectively to cut off the fire in the precontrol stage or to check for any lingering fire after control has been established. When a fire enters a cockloft, the best way to check its spread there is to open up the roof directly over the channel carrying the fire up into the cockloft. If fire is spreading horizontally in ceilings on intermediate floors, openings should be made ahead of the fire and hose lines operated to cut it off, working back toward the area of origin. This technique is never used, however, if it entails passing the fire and thereby cutting off a *required* means of escape. A knowledge of structural parts in such work is essential. The officer should not only be familiar with all the potential avenues by which a fire may spread, but he should also know what channels are most apt to be involved in specific types of construction.

Fire officers should know if standpipe, sprinkler, or other fixed systems are present and how they may be used at maximum efficiency. They must know the location of the means by which these systems are supplied by fire apparatus, the location of stairways in which standpipe risers are located, the location of control valves and how to use them, particularly in relation to sprinkler systems, and what assistance can be given by persons legally in charge of the systems.

It is dangerous to operate from the outlet at the fire floor; with rare exceptions, the outlet below the fire floor should be used. There are many kinds of fixed systems, but only general discussion is appropriate here.

The height of the fire building, and of the fire floor, as well as the heights of exposed buildings may indicate a need for special apparatus such as the water tower or for apparatus with ladder pipes. Height may rule out the use of an aerial ladder for rescue purposes, may influence

the exposure hazard, may make dependence on the standpipe system mandatory, etc.

The area of the occupancy involved is important, since large areas, especially when undivided, abet the spread of fire and the development of high temperatures. Heavy-caliber high-pressure streams may be needed, as well as additional help to cover what may prove to be a fire with a large perimeter.

Concealed spaces often play a key role in fire spread. It is obviously impossible to know the exact number and location of concealed spaces by which fire travels through a structure. It is possible, however, to know if such spaces do exist and to anticipate the results. Signs of heat and smoke at some distance vertically or horizontally from the fire's origin, generally perceptible by sight, touch, hearing, and smell, indicate that fire is spreading through concealed spaces. The most commonly used way of checking is to feel suspected walls, partitions, and floors with the hands. Where concealed spaces are amply involved in fire, radiated heat will be felt. Fire extension is less often detected by smell and taste because of the increased use of masks.

Visible evidence of fire in concealed spaces may be in the form of smoke issuing through cracks in floors, walls, and partitions or discoloration and blistering of paint; hidden fire in a cockloft may be detected by the emission of smoke from cornices, melting snow or steaming on a wet roof, and blistering of tar.

The sound of crackling flames in walls, partitions, ceiling spaces, or cocklofts is a convincing message that fire is there and moving rapidly. Where the supply of air in concealed spaces is more limited, the fire will spread more slowly and a much heavier smoke condition will develop.

In connection with concealed spaces, the "sixth sense" deserves mention. Some officers have an indescribable ability to open up a structure in the right place and at the right time to check extension of the fire. Perhaps, however, this sixth sense is a rare combination of knowledge, experience, and judgment.

Structural Collapse. Structural collapse is obviously a topic of great concern to firefighters. In assessing the threat of collapse, an officer should give careful consideration to the type of construction involved in the fire (nonfireproof structures are very susceptible to collapse and have presented some of the most serious problems); age of the structure (age intensifies structural defects); duration of the fire (how long have the structural members been burning, and how much water has been poured into the building?); location and extent (the fire may be located where it will quickly weaken structural members, and weakening is more likely if the fire is extensive); conditions on arrival, particularly where an explosive smoke or back-draft condition is present; presence of heavy

machinery or dangerous floor loads; nature of the burning or exposed contents (are they absorbent, explosive?); proper supervision (the stairs must not be overloaded); the span of floor between supporting members (wide spans are more susceptible to collapse); and whether supporting metal structural members are unprotected (they may rapidly fail if heated and then struck by cold water from streams, a more likely possibility if cast-iron columns are present).

Signs of imminent collapse are a rumbling sound that may accompany a wall disturbance or collapse, cracking or bulging of walls, water or smoke seeping through the walls, twisted or warped columns and beams, and floors sagging or pulling out from walls. It is folly, however, to wait for these signs to occur before taking precautions. Fire personnel are best safeguarded when the officer assesses the threat of collapse early and with care, considering the factors just listed.

Types of Construction

This discussion obviously must be selective, because only a few of the innumerable types of construction can be considered here. The types discussed have been chosen in order to give a broad, cross-sectional view that will enable a fire officer to evaluate the problems created by any type of construction. The multiple-family structure has been deliberately omitted, since there are so many types that it is hard to present useful generalizations.

The most prominent type of construction for large buildings today is curtain-wall construction.

"Curtain wall" ("panel wall" in some codes) has come to mean a wall that divides space, is controllable, and supports nothing but itself. With the introduction of steel and reinforced concrete framing, the ancient function of the wall as an integral part of the primary structural system was eliminated. Supplanted as vertical supporting members by structural columns, bearing walls became obsolete. The modern curtain wall was developed to take its place. Primarily, it must enclose space; it must support only its own weight, usually for one story, occasionally for two or more; and it must do everything any wall does except support the floors, roof, and other walls.

When fire protection is designed into a curtain wall, fire must be prevented from entering the building from outside, it must be prevented from spreading from the inside to other nearby structures, it must be prevented from spreading from one floor to another or from one room to another by passing through the exterior wall and back into the adjoining space, and smoke and gases must be controlled.

The curtain wall has advantages for the fire service: The building will be erected more quickly, reducing the period of fire hazards in buildings under construction; the hazards inherent in demolition work will be reduced, since this process will also be quicker; there will be less obstruction from trucks and stored material at the street level, which at times blocks hydrants and hinders placement of apparatus.

Fireproof Buildings. Building-code requirements for fireproof construction vary throughout the country: some codes require exterior walls having a four-hour fire-resistive rating, and other codes accept less than four-hour walls. All codes recommend a minimum of combustible material and maximum firestopping material, and the spread of fire from floor to floor in these buildings is rare. The records indicate, however, that some extremely costly (in lives and property) fires have occurred in "fireproof" structures.

Forcible entry can be difficult in these structures at night, since doors are generally locked then and some of these doors are sturdily built. Efforts to enter by other means may cause delays. Larger fireproof buildings invariably have night watchmen, but they frequently go to the fire floor and are not on hand to open doors for the fire department at the street level. Even if a street door has been left open, there is often delay in getting a much-needed elevator. Fortunately, many large hotels have effective fire procedures; elevators are generally ready at the main floor to convey men and equipment quickly to the fire floor.

Rescue work is often more difficult because the life hazard can be severe for occupants, particularly in windowless structures. Many persons do not know the location of fire stairs and have small chance of finding them in the smoke and heat of a fire. This is true of employees in large fireproof office buildings and particularly of guests in the larger fireproof hotels.

Rescue operations are made more difficult if aerial ladders cannot reach some floors. Also, the long corridors (in hotels and many office buildings) by which occupants have to be reached get extremely hot and smoky. Visibility is poor, and ventilation of such corridors is slow and troublesome, especially if the building is air-conditioned and windowless. The life hazard for occupants on the floor above the fire is seldom severe; in many cases, these persons need not be removed. If removal is necessary, a clear stairway should be used, that is, one not being used to stretch a line. Opening the stairway door on the fire floor may create a draft, with an inrush of smoke that will make descent from above difficult.

Ventilation must be horizontal rather than vertical in most cases. When a corridor is vented by opening doors and windows at both ends, conditions will be much better on the windward side. Lines should be

advanced and rescue work performed accordingly. Elevator shafts are not specificially used to vent, but smoke will enter and ascend, necessitating an examination and possibly a smoke-clearing operation at the top.

Fires are generally confined to the floor, and in many cases to the room, of origin, largely because of incombustible construction and effective fire-stopping material. Fire operations are almost invariably interior.

Tight fireproof construction retains a high percentage of the heat generated at a fire. This makes it difficult for firefighters trying to advance a line down a long corridor, especially when working into the wind with the door open to the involved area. Many masonry materials slow down the rate of heat transfer because they contain large quantities of trapped water, which is evaporated by the heat. Large amounts of heat can be stored in these materials during fires; and it is radiated for a surprisingly long time after the fire has been darkened down.

The ultimate effect of fireproof construction is that fires are generally brought under control more quickly and with less manpower and equipment. Overhauling is usually less extensive and is confined mainly to the contents. Thus, fire-service units will be out of service for shorter period of time, assuring better overall fire protection.

Air-conditioning Systems. Air-conditioning systems are frequently present in fireproof buildings. Until recently, many places lacked effective laws to govern installation and alteration of systems. This resulted in lack of standardization at least, and many shortcomings for the most part. Ducts were dangerously near to combustible materials, which in time become susceptible to ignition. The complexity of some systems and the inaccessibility of some ducts made it difficult to locate and attack the fire. Access openings were inadequate in number and location, handicapping the fire service. Dampers were also inadequate in number and location so that when the system was involved in fire, all the problems caused by concealed spaces were present, accentuated by good air supply and what amounts to an open road for the fire to travel.

Before the arrival of the fire department, fans undoubtedly are operating. This accelerates the rate of combustion and the spread of fire throughout the system. Fans in some cases are located unfavorably (from the fire-service viewpoint) in rooms, on the roof, or in basement floors. Where air is recirculated, fans should be shut down automatically by the action of a thermostatic device in the air-return duct. These devices can be set to operate at predetermined temperatures.

Many systems have ducts extending through several floors and fire partitions. The location and operation of automatic fire dampers can do much to isolate the fire. They are particularly appropriate where the ducts pass through fire walls and partitions and at openings in the vertical main duct where it serves branch ducts on various floors. Inlets

in the exterior walls expose the system and the building to heat and smoke from fires in the vicinity. If necessary, the shutters at the exposed fresh-air intakes should be closed. This procedure is particularly important if the exposure is a hospital or theater. Combustible materials, such as cotton, paper, steel wool, and felt have been used for filters, many of which are coated with high-flash-point oil to catch the dust. Combustible filters and combustible dust are the ingredients for a hot fire. Some portions of the ducts are lined to reduce the transmission of undesirable noise or to cut down heat transmission through the duct walls. In some instances, the lining is combustible.

Coils containing a toxic or flammable refrigerant have been inserted in air passages in some systems. This intensifies the life hazard in the event of a leak, since the refrigerant gas is distributed throughout the ducts.

Windowless Buildings. Many fireproof buildings are windowless. Practically all of what has been said above applies to windowless buildings. Buildings whose windows have been bricked up during alteration work are not included, as many of these are nonfireproof.

In a fire, windows can provide means of rescue, permit smoke and vapors to vent to the outside, permit early discovery of fire and transmission of alarm, allow fresh air to reach occupants, provide vantage points for firefighting attack, and allow heat to be dissipated more rapidly, thereby helping prevent consumption of the structure.

In windowless structures rescue work is hindered because the endangered occupants cannot show themselves at windows, cannot be covered by lines from the outside while awaiting rescue, cannot be reached or removed by aerial ladders, roof ropes, snorkels, or fire escapes, and cannot be aided by the type of ventilation usually employed to assist rescue efforts. Such ventilation consists in utilizing structural or other openings to draw heat and smoke away from trapped occupants awaiting rescue. Where smoke-removal systems are installed, it is important that they are arranged to keep smoke away from the exit.

Ventilation cannot be used effectively to aid in rescue work, nor can it be used effectively to control the direction of the fire by localizing it, as can be done at fires in nonfireproof structures. In addition, smoke elimination may be slow, impairing salvage work, increasing smoke damage, and necessitating the use of gas masks for prolonged periods of time.

Artificial lighting may fail during a fire and plunge the interior into total darkness, even in the middle of the day. This is conducive to panic and greatly adds to the problem confronting the fire department.

One code requires sprinkler protection for windowless buildings over two stories in height or 2,000 sq ft in area on any floors above the first

or ground floor that lack suitable access to each story above the basement on at least one side of the building. Suitable access is defined as requiring an opening in the wall for fire-department use at each story at least 32 in. wide and 48 in. high, with the sill not more than 32 in. above the floor. The openings are to be spaced so that there is one in each 50 ft of exterior wall on an accessible side of the building.

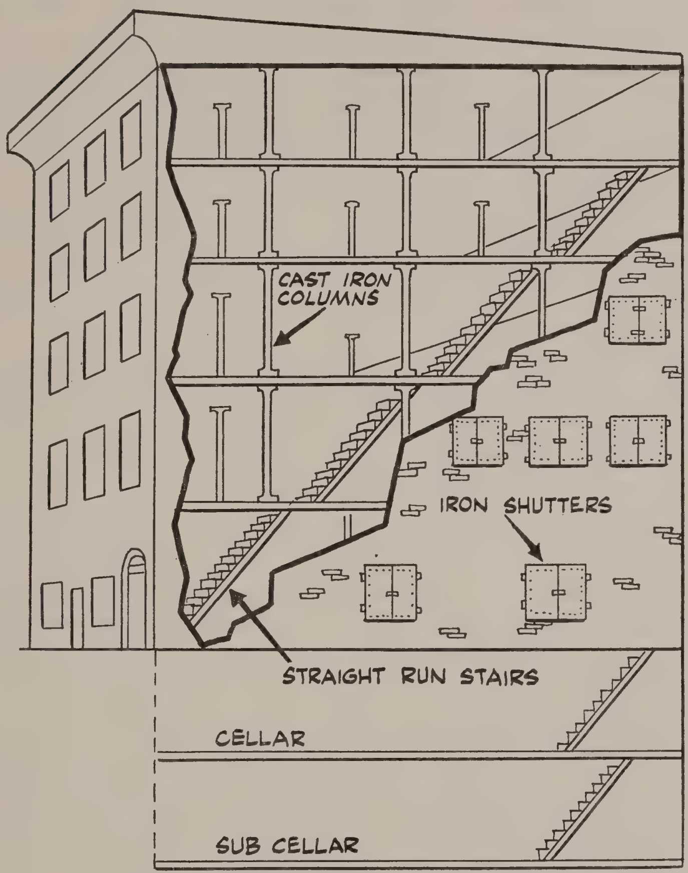

FIG. 6-1. Nonfireproof commercial building.

Nonfireproof Buildings. These structures have combustible structural members that burn readily, they lack fire-stopping material, thus enabling fire to spread quickly both horizontally and vertically, and frequently they are old, which aggravates structural defects. Old-type loft buildings have additional unfavorable characteristics: subcellars, unusual depth (in some instances, 200 ft), unprotected metal structural members, wide floor spans, iron shutters, etc. Much of the following discussion is pertinent to loft buildings.

Sizing up the fire situation in such structures may be extremely difficult. Fires in cellars or subcellars, even though minor in extent, may be troublesome to locate because of limited means of ventilation and approach. On occasion, these fires are stubborn and can extend rapidly; hence, the commanding officer should guard against reporting prematurely that such fires are under control. At fires above ground level, sizing up is comparatively easier, particularly during business hours.

At these fires there is the ever-present possibility of structural collapse. Information must be weighed with exceptional care before initiating operations. Of course, where life hazard is present, more than average risks by fire personnel may be required. Some authorities recommend an exterior operation when two or more floors of the building are fully involved in fire. This is a sound recommendation, but the author suggests that circumstances such as wide floor spans, hazardous contents, long duration of the fire, age of the building, the presence of heavy stock or machinery, etc., may make an exterior operation advisable even before the fire reaches that extent.

Forcible entry seldom presents a problem during business hours. At other times, entry is hindered by iron shutters on some windows and by locks on doors to individual occupancies that are often intricate in design and somewhat difficult to force.

Rescue work at fires in lofts is often impeded for the following reasons: contents are often combustible and fast-burning in factory occupancies, and high temperatures can be expected; severe smoke conditions may develop, impairing the visibility of occupants seeking exits and of firemen seeking occupants; floor conditions are crowded by work benches, chairs, machines, and material, even when complying with the law (only a 3-ft aisle space is required in some instances); frequently there is a large number of employees, many of whom are women; exits may be unfavorably located, particularly above the second floor. Some exits are about 40 ft in from the street front because the stairs run straight from the street level to the third-floor landing. These exits may be located in the heart of the fire, thus making impossible either exit by the occupants or entrance by firefighters. In such cases a ladder pipe could be operated through the street-front windows long enough to make possible entry with a hand line (two lines if conditions warrant) into such floor areas via ladders or even the interior stairway. Entry for rescue follows.

Ventilation, a potent weapon for minimizing the life hazard, cannot always be employed effectively and in time unless the fire is favorably located or a roof opening can be quickly made to draw heat and smoke away from the life-hazard area.

In some situations, the search for occupants overcome by the fire is hindered by severe smoke and heat, poor visibility, congested floor

conditions, lack of effective ventilation and hose streams, and the unusual depth of the structure. Occupants may be found conscious but so panic-stricken that their removal becomes unusually complicated. Some become fearful and, unless strongly urged and guided, seek safety elsewhere, often disastrously. Properly conducted fire drills are extremely important in these occupancies. Well-trained personnel can do much to prevent the holocausts too often associated with loft fires.

Where a life hazard is present, the first line is stretched and operated as quickly as possible between the fire and the endangered occupants or between the fire and the means of escape, just as at any other fire. Subsequent lines are placed in accord with the principles applicable at all fires.

Where no life hazard exists, lines are placed according to principles discussed in Chap. 10. In some cases, the first line is stretched up the interior stairway to execute a holding action while the second line is brought up the fire escape to put out the fire. This is an acceptable variation of the usual procedure (operating line from the interior) due to the unusual depth of some buildings, if the location of the fire is favorable for such a technique. Auxiliary equipment (sprinkler, perforated-pipe, etc.), if present, must be supplied as conditions dictate. The correct inlet must be supplied, or unwarranted and severe water damage may result. At low-level fires the correct inlet may be chosen by feeling for heat conducted from the fire area by connecting piping. The location of the fire within the building may be revealed by this technique if inlets are properly marked.

Ventilation to extinguish the fire is greatly hampered by iron shutters. Sometimes conditions conducive to a smoke explosion are present. In such cases, it is of the utmost importance to vent at the roof before opening up at lower levels. Where the possibility of an explosion exists, the commanding officer must see that sufficient help has been called, that lines are stretched and ready, etc.

The exposure hazard at loft fires is great to the fire building itself and to other buildings. Fires can spread rapidly from floor to floor. In some cases, the extent of the fire rules out interior operations; in others, interior operations have to be abandoned because of the danger of structural collapse. The exposure hazard is intensified because lofts are often located in congested neighborhoods in which the buildings nearly abut.

The unusually risky nature of operations at loft fires requires extremely careful supervision. Entire fire companies have been injured or killed by falling through collapsed roofs. All officers should be keenly alert to the possibilities of collapse so that men can be removed in time, and effective communication should be promptly established so that all units can be quickly contacted.

Buildings with Fire Escapes. As a general rule, forcible entry is more readily and quickly effected in structures provided with fire escapes, since the disadvantage presented by strong locks and doors is eliminated. In addition, much less property damage is usually done.

Ventilation of an entire building can be carried out with comparative ease and speed by means of fire escapes. By contrast, when fire escapes are not present, ventilation may be a difficult, punishing, and time-consuming process, especially when the fire and the exposed floors are beyond the reach of, and otherwise inaccessible to, aerial ladders. This is true not only of fires on high floors but also of those on lower floors (but beyond the reach of portable ladders) of many modern multiple-residential projects where aerial ladders are practically useless because the trucks cannot be positioned properly.

The annals of the fire service abound with reports of rescues made by firefighters entering fire floors and exposed floors and removing endangered persons. In some cases, entry, search, and removal are accomplished without the protection of hose streams, which are not yet operating. Such rescues are made possible in many cases because fire escapes are present. On many occasions, occupants have saved themselves by using fire escapes before the fire department arrived. Some people contend that fire escapes are not feasible on high buildings because the ordinary person is reluctant to use them at such a height, but this objection overlooks the remarkable feats of which an ordinary citizen is capable during fire or similar emergencies. The Hotel Winecoff fire (Atlanta, Georgia, Dec. 7, 1946) is an outstanding example of such ability. More than one person lowered himself several stories down the outside of the building by bed sheets, and from fairly high levels.

Fire escapes are a great asset in stretching and operating lines. Experience has often shown that a line advanced from the fire escape can put out the fire when lines from the interior cannot be moved in. It is helpful to have the option of attacking the fire from either side instead of only from one. Where there are no fire escapes, the fire officer may have to choose between advancing lines from the interior, with considerable hardship for fire personnel, or using heavy-caliber streams from the ground level or from upper levels of adjoining structures. In effect, the absence of fire escapes compels an officer to resort to exterior operations more frequently, and such operations almost invariably result in greater property damage.

Frequently, at greater-alarm fires, fire escapes have been used as vantage points from which to operate lines for defensive or offensive purposes or both. Such vantage points may obviate the need to force entry into surrounding structures.

The primary purpose of a fire escape is to provide a way by which the

occupants of a building can escape in the event of a fire or other emergency. A subordinate purpose, when the safety of the occupants is not jeopardized thereby, is to furnish the fire department with a means of advancing into an involved or exposed building to extinguish fires and protect exposures. Fire stairs fulfill the primary purpose better than a fire escape only where they are equally accessible. As a matter of fact, in many modern apartments without fire escapes, fire stairs are useless if the occupant is trapped in his apartment.

Buildings under Construction. Fires in these structures often occur at night, with attendant disadvantages (Chap. 5, Night Fires). During the day, rescue work is not usually a serious problem, since the average workman can quickly get out of harm's way. If the fire is at night, however, one or more watchmen may have to be looked for. The hazards at fires in buildings under construction, already great, are intensified at night.

There is always the danger of timbers falling from topside. The exposed steelwork on top may buckle, weakening the structure. The concrete beams and slabs on upper stories may not be set; if the wooden supporting forms burn, the floors may drop. Exterior bridging and scaffolding may interfere with the use of aerials to enter and stretch lines, necessitating the use of unfinished stairways of questionable stability, and may also prevent the stretching of a line to upper floors via the outside of the building, making the stretch much more time-consuming and arduous.

Officers ought to be aware that hoists for materials are not intended to transport men. If possible and feasible, however, they can be used to convey rolled-up hose and other equipment that may be needed at upper floors. Where elevators designated for fire-department use are required and provided, it is preferable to use them.

When hose lines are being advanced, floor openings must be watched carefully, as some may be protected by inadequate guard rails. Tanks containing flammable gases for use in operating cutting torches or dangerous gases for heating purposes may be present, greatly increasing the life hazard for fire personnel. Cartridges may be used in riveting, adding to the perils. Paints, oakum, excelsior, interior wooden scaffolding, tarpaulins, etc., are all fuel for a fire of serious magnitude.

Most construction fires are minor when discovered because of the open construction and resultant comparatively quick detection. They may become major fires because of the large amount of combustible material and the rapidity with which such fires spread, and possibly because of abnormal delay in getting water on the fire. The combustible material may be debris, wooden chutes, sheds, shanties, or concrete forms. The spread of the fire is abetted by the open construction, ample

supply of oxygen, and any prevailing wind. If the building project is extensive, the fire can likewise be large and will present proportionately greater problems in stretching, placing, and using lines. Principles governing the placement and use of lines (Chap. 10) apply to fire in buildings under construction, with variations warranted by the circumstances.

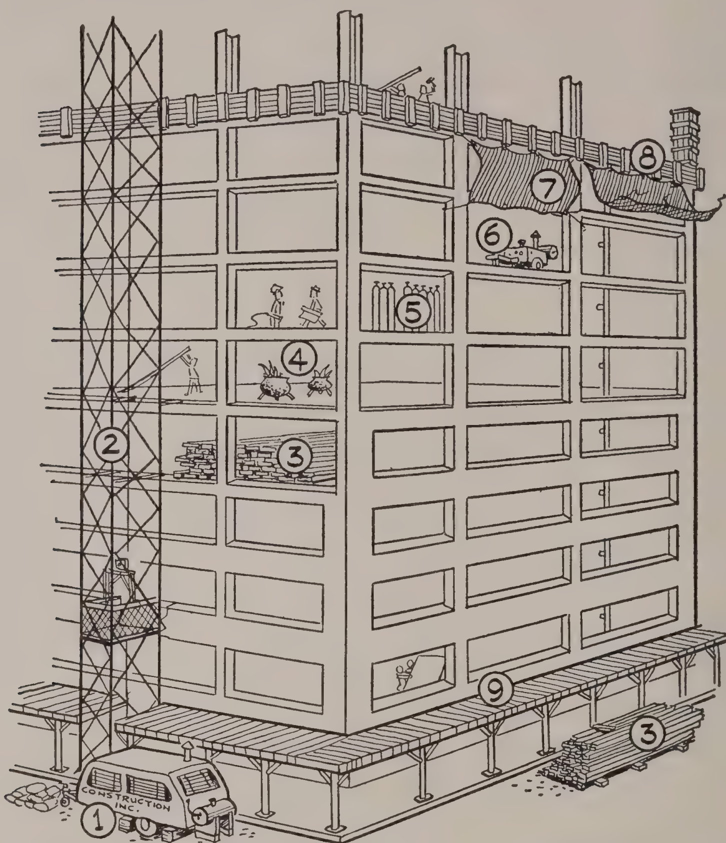

FIG. 6-2. Hazards of a building under construction: (1) flammable gas for heating; (2) hoists, dangerous to use; (3) lumber; (4) salamanders; (5) tanks of flammable gas; (6) gas heaters for drying; (7) tarpaulins; (8) wooden forms; (9) wooden bridging.

For example, the location of the fire, its height, inoperative standpipe system, or lack of elevator service may, in the case of a one-line fire, cause the officer to consider other alternatives than the interior approach.

A minor fire can sometimes be kept in that category by the prompt use of the deck pipe or similar equipment. In addition, there are cases on

record where streams from deck pipes and water towers have been used effectively on high fires in buildings under construction. Such streams can be particularly useful if fog is used from the windward side of the fire.

A fire that actually requires only one stream for extinguishment may necessitate the use of a full first-alarm assignment, since, among other things, stretching the line may be a laborious process, requiring much manpower.

The exposure hazard at construction fires may present some major problems. In addition to convection and radiation of heat, high-flung sparks and embers are present. The use of lines will be affected by the severity of the exposure hazard, the presence or absence of life hazard in the exposed buildings, etc. The commanding officer naturally takes into consideration the location and extent of the fire, the construction and proximity of exposures, the direction and velocity of the wind, the availability of auxiliary equipment in the exposures, the capacity of the assignment on hand and available on call, and other related factors (Chap. 5).

In some localities, standpipe systems are required under certain conditions, for example, when floors are in place above the seventh story or more than 75 ft above the curb level. Very often, these systems prove undependable at night because of carelessness about closing valves that have been opened during the day. Elevators for the use of the fire department may be required when the building has reached a certain stage. When elevators are installed, watchmen should be provided to operate them. Fire guards may be required if hazardous cutting torches are used. Sparks from cutting torches and from illegal fires started by workmen to keep themselves warm in the cold weather are fire hazards, particularly where canvas tarpaulins and other materials so susceptible to ignition are near. Fires in salamanders, although legal, increase the hazard.

The use of explosives poses a problem that is somewhat alleviated by careful surveillance and competent watchmen. Explosives are generally only needed in the very early stages of construction. Some fire departments, as a precautionary measure, prohibit the use of radio transmitters on department vehicles within 150 ft of magazines containing explosive caps because at close quarters radio waves may energize the detonating mechanism.

Buildings under Demolition. Much that has been said about buildings under construction applies to those under demolition. For example, the fire department may encounter difficulty in getting water to high fires if the standpipe system has been put out of service during the demolition

process but the structure is still fifteen stories in height. In some cases, contractors using modern techniques just peel off exterior walls, remove undesirable partitions, and erect a new building on the metal framework of the old. Almost invariably, no elevator is reserved for fire-department use during demolition. This is a serious handicap when the fire is on a high floor, but the handicap might be offset by effective building-code legislation.

Possibly the greatest problems caused by demolition are found in slum-clearance projects. Fires of unusual extent and type can be anticipated, and unusual aspects of the life hazard must be kept in mind.

Some tenants, mostly older persons, are uncooperative about moving away from old friends and neighborhoods in the interest of slum clearance. They remain as long as possible. Their reluctance is understandable, but their isolated presence is hard to detect since large areas and numerous houses may be involved in the project. In addition, vacated buildings become havens for vagrants and, in some cases, hangouts for teen-agers. Both these groups may create an unsuspected life hazard, and they definitely create a fire hazard, since in partly vacated houses gas may still be supplied.

Exterior operations will be resorted to more frequently when it has been ascertained that there is no life hazard because (1) fires are often of sufficient extent to warrant such an operation and (2) firefighters may be necessarily jeopardized in an interior attack by weakened stairs, holes in floors, etc. In some instances, windows are boarded up or covered with sheet metal, impairing ventilation and visibility and increasing the dangers.

The buildings being demolished may be of nonfireproof or frame construction, and piles of combustible debris may accumulate to a dangerous degree. Official permission is granted in some communities to burn this debris under specified and controlled conditions. Unless stringent surveillance is exercised, contractors may ignore controls and try to burn the material in larger volumes than the law allows.

A slum-clearance project may include several blocks of buildings. Fires are often extensive when the fire department arrives and in many cases are of greater-alarm proportions. Some fires, started legally to burn debris, are buried under tons of brick, evidently thought to be extinguished when the contractor left at the end of the day.

The use of bulldozers at demolition fires may minimize the hazard to fire personnel in the overhauling phase by exposing brick-covered fires that would otherwise entail a long operation to extinguish.

It may be noted in conclusion that slum-clearance projects have an advantage for the fire service. They provide excellent locations for practical drills and training exercises.

Buildings under Alteration. Alterations are not always effected in accordance with the law or with recommendations in nationally recognized codes. As a result, newly created areas may be too large, metal structural members may be unprotected, and openings in dividing walls may not be sufficiently fire-resistant to prevent the spread of fire. The fire department is thereby faced with the possibility of an extensive fire and, ultimately, structural collapse.

Alterations within a structure can increase the number of concealed spaces by various kinds of falsework, double or triple flooring, etc. Fires travel readily through such spaces, often making it difficult to ascertain accurately the location and extent of the fire and the best place to vent or to open up the structure in order to cut off the fire. Fires in such structures are frequently characterized by severe smoke, which reduces visibility and the efficiency of an operation despite the use of masks. In addition, the burning space may be very inaccessible.

Piers. *Older Piers.* Records show that operations at major pier fires generally are far from successful, even if the commanding officer is familiar with structural features. This lack of success is usually due to the obstacles inherent in pier construction rather than to inefficiency of the fire department.

Sizing up the situation may be very difficult at pier fires, particularly if the substructure is burning, as is the case at many major pier fires. Obstacles to assessing a fire in a pier substructure include impaired visibility due to dense smoke and inaccessibility due to planking or railroad siding surrounding the outer periphery of the bulkhead pier structure.

Delay in correctly estimating the situation at substructure fires will cause a corresponding delay in getting an effective operation under way. To solve a problem, one must first be able to define it. In the meanwhile, an officer must decide where a defensive line should be established if it becomes necessary, while simultaneously trying to cut off and extinguish a fire that is unseen, of unknown extent, and probably traveling. The kind of decking, availability of equipment required to make necessary openings, time needed for the job, wind velocity and direction, apparent rate of fire extension, necessity of establishing the line sufficiently in advance of the fire, and, above all, the safety of the fire force will influence an officer's decision about a defensive line. Transverse fire walls in the substructure of some piers also are important.

Placing and using lines to confine, control, and extinguish pier fires is complicated by many factors. The combustible structural parts in both substructure and superstructure provide plentiful fuel. The usual large undivided areas are conducive to rapid spread of fire and the development of high temperatures, aggravated at times by the height of some pier enclosures. Hot gases may accumulate below the roof, ignite, and

cause rapid horizontal spread of fire unless this development is anticipated and promptly attacked with a battery of heavy-caliber streams. If this protection is not provided, personnel and apparatus on the pier may be endangered.

The shape of many piers limits the avenues of approach so that land engine companies can attack from one end only, thus hindering effective placing of lines. In addition, an attack by fireboats may be impeded by sheds if the fire is in the superstructure, by high tide if the fire is in the substructure, by strong tides that make it difficult to maneuver in narrow slips, by ice accumulations, and by ships tied up at piers. The inaccessibility to attack of fire in the substructure is magnified by cribwork, which further reduces the efficiency of streams.

The exposure hazard is a critical one, especially if the substructure is involved, since the oil-covered and creosoted piles burn persistently and the usually prevailing waterfront winds intensify the fire and accelerate its spread. Moreover, some vertical openings on piers and in bulkhead structures lack adequate fire-resistive protection. Thus, vertical as well as horizontal spread of the fire is a threat.

Ventilation of the superstructure at serious pier fires is best achieved by fireboats using heavy streams where such a technique is possible. Manual ventilation could be too hazardous and is of questionable effectiveness. In some cases, operations may have to be initiated without the great advantage of adequate ventilation, since manual efforts may be impossible and fireboats may be slow in arriving.

The life hazard for firefighters is high, with injuries including smoke inhalation, exhaustion, inflammation of the eyes, falls, and submersion. The commanding officer must be always alert to the possibility of being outflanked by fire in these situations and cut off. The fire may sweep overhead in the superstructure or break out behind the defensive line when the substructure is burning.

Waterfront strikes intensify the severity of pier-fire hazards. Tugboats, so helpful in removing endangered shipping, may not be as readily available. Likewise, longshoremen, who can give considerable help in many ways, may be absent. Invariably, during a strike piers become increasingly congested with cargo. In heavily congested piers standpipe outlets and openings in decking (for use of distributors, etc.) may be inaccessible; cargo may be piled so high that the efficiency of sprinklers is impaired and penetration by streams limited; aisle space may be inadequate, a severe handicap where long hose stretches are necessary because of lack of standpipe outlets; regulations governing storage of dangerous cargo may be less stringently enforced, increasing all existing hazards; and ships will be tied up longer at piers, increasing the exposure hazards.

Modern Piers. In contrast to the decidedly unfavorable structural features of older piers, it is interesting to note the fire protection on the new piers being built by the Port Authority of New York.

A concrete pier deck has timber piles with concrete extensions from the mid-point of tidal range to the underside of the deck. Construction meets underwriters' requirements for fire-resistive rating. The shed has steel columns, steel roof framing, and aluminum siding and roofing. An apron width of 30 ft permits passage of fire apparatus around the pier. Smoke and heat vents will be quickly provided by plastic skylights, constituting 5 to 6 per cent of the roof area, which will burn away at temperatures of 800 to 900°F. "No Smoking" signs are permanently displayed on the lower part of the trusswork, approximately 200 ft apart. Signs also indicate the location of sprinkler control.

The sprinkler system installed is a 12-in. service, dry-pipe preaction system with dry-valve accelerators, outshore exhauster, rate-of-rise system operation, and automatic supervision. Approximately 118 sq ft are covered by one sprinkler head. There is a water-flow alarm, which causes fire-alarm signals to be quickly transmitted to the fire department. Siamese connections to supply the system are advantageously located. Booster fire pumps to be used are rated at 1,500 gal per minute at approximately 90 psi differential pressure, and they are to be connected to the sprinkler system and the hydrants. Fire hydrants are located at the inshore end of each pier. Electric booster-pump stations are strategically located throughout the area.

The standpipe system installed is a 6-in. service, electrically heat-traced wet-pipe system. The hose stations have 1½- and 2½-in. outlets, and the number of stations is determined by the area of the pier. The standpipe system is also arranged to supply domestic and ship's water through pressure reducers. Fire-alarm boxes transmit signals to a central office and thence to the fire department. About eight proprietary fire-alarm boxes per berth are provided in the pier shed, and at least one public fire-alarm box is provided on the face of each pier. Fire extinguishers are provided in the ratio of one for each 2,500 sq ft of pier-shed area.

An effective lighting system on these piers facilitates efficient supervision and expedites fire detection by watchmen.

These piers are one story high, thus eliminating the hazards of high sheds in older piers. The new piers are 12 ft above mean water level, 2 to 2½ ft higher than the pier decks on older piers. This extra height above water may prove important when an examination of the substructure is necessary.

The width of slips in the new project ranges from 280 to 300 ft compared with the present 200 ft. The extra width will expedite docking

and departure of vessels and, when necessary, will facilitate fireboat maneuvering.

Street conditions will be greatly improved. Trucks will be either on the pier or in paved areas on the inshore side. There will be no cargo storage on the street; it will all be stored in the ample upland area provided.

Although newer piers have a much larger area than many older piers, the hazards generally inherent in large-area occupancies are offset to a considerable degree by many of the features mentioned. The plentiful space on these piers ensures adequate room for trucks to maneuver, and freight will be handled better and more quickly. Quicker turnover of cargo will reduce the hazard caused by freight storage.

The built-in greater-alarm structural features of older piers are conspicuously absent in the newer ones. The problems of substructure fires have been minimized, if not totally eliminated. This, in itself, is a major accomplishment. The fire hazard in the superstructure is reduced also by modern fire-detecting and fire-protection equipment, by better accessibility for fire apparatus, by better venting possibilities, and by fireproof construction.

Ships. Since there are many types of ship construction, this discussion must also be selective. At the same time, ship fires present varied and difficult problems, and it is hard to generalize. For example, the problems at the recent fire on the aircraft carrier "Constellation" in the Brooklyn Navy Yard defied solution for many hours despite practically unlimited manpower, equipment, and water supply.

The type of ship discussed in this section is the passenger-cargo ship. Although this vessel does not necessarily present the most troublesome fire situations, it is very challenging because of the multitude and variety of hazards.

Ship Construction. Passenger vessels are of many types. The luxury class is built for speed and luxury and carries comparatively little cargo. Some ships have as many as twelve decks and are more than 1,000 ft in length. However, many well-known passenger vessels have space for enormous cargoes.

On passenger vessels, the interior decks are almost universally designated alphabetically, A deck being the highest deck on which passenger staterooms are located. The exterior decks are generally known as the sun deck, the sport deck, the boat deck, the promenade deck, etc. In the American system, holds are numbered beginning with 1 at the bow and proceeding to the stern. Some nations number the holds in reverse order. Firefighting equipment and appliances on shipboard are specified by the particular nation with which the vessel is registered. In this respect, there may be a lack of uniformity.

There is plenty of material on board passenger-cargo vessels to supply

fuel for a hot fast-burning fire: much of the superstructure is combustible; considerable combustible falsework may be found in some staterooms; ceilings and decks are often combustible, with untreated wood furring; furniture and furnishings are flammable, as some cargo may be; cabins or other class B bulkheads within class A bulkheads are usually constructed of untreated wood with painted or unfinished surfaces.

Class A bulkheads are similar to fire walls in other structures (fire walls provide maximum resistance to the spread of fire as compared with fireproof or fire partitions). They are designed to prevent spread of fire to critical areas by forming enclosures around vertical openings and storage, cargo, and working spaces, and on some passenger ships they are spaced about 131 ft apart. Class B bulkheads offer less fire resistance and are used for stateroom and other enclosures within main subdivisions formed by class A bulkheads.

Fires in some parts of passenger vessels (locker rooms, cargo holds, engine rooms, etc.) are often inaccessible to attack because of difficulty in venting. Lack of ventilation, in turn, increases the hardships of advancing a hose line to extinguish the fire. To ventilate in some cases, side plates must be cut and decking opened up. Fire operations at the lower levels may receive very little benefit from ordinary ventilation methods.

The hazard of fire extension is great because so much of the construction is open. If the ship is at sea, strong drafts will generally prevail throughout the long corridors and passageways (corridors run the length of the ship on the port and starboard sides, and passageways lead from the corridors to the cabins). Frame and deck beams in the cabin area may be covered by decorative paneling, resulting in concealed spaces 7 to 9 in. deep through which fire can spread unseen. Such concealed spaces are particularly dangerous when they enclose cables and piping and extend the length of the corridors. Fire may also extend behind paneling into the space between deck beams and thus travel to the other side of the ship. When a fire starts moving behind decorative paneling in the large public rooms, sprinkler systems may be ineffective in checking the spread. Extensive ventilating systems with their numerous ducts may also abet the spread of fire.

At fires below deck, heat may be conducted through decks, side plates, and bulkheads; heat radiation may extend the fire further. When the ship's plates indicate (by blistering of paint, smoke, reddening of the metal, etc.) the progress of the fire, they should be cooled by streams to prevent bulging, warping, possible opening of the seams at the water line, and involvement of the pier by radiated heat.

Rescue operations are complicated by structural features. Heavy heat and smoke conditions can readily develop, making affected passageways and corridors dangerous mazes conducive to panic. At sea, means of

escape may be limited to lifeboats and lifebelts. Weather conditions could make rescue by such methods exceedingly difficult and hazardous. Of course, it is very unlikely that a fire department will be presented with such a problem, since almost invariably it is called to fires in vessels tied up at a pier.

In trying to define the problems, the fire officer deviates from the usual pattern of depending on his high-ranking subordinates for information. Fire-department officers seldom have an opportunity to inspect ships and familiarize themselves with the features of construction. Ship officers should be contacted for this information. The fire officer will want to know whether cargo doors or port holes are open, if the watertight doors in bulkheads are secured; whether the ship can move under its own power if necessary, what steps have been taken by the crew to extinguish the fire, and what auxiliary equipment (carbon dioxide, steam systems, etc.) has been used or is available. The ship's plan, which is generally in the chart room, the captain's office, or the ship control station, will be helpful. In addition, the stowage plan can be discussed with the first officer to find out, in the event of a cargo fire, what material is burning and how it is stored. The fire officer should also check for recent or present fumigation and the possibility of having to contend with other harmful gases.

Stretching and using hose lines may be a difficult proposition. Ship mains, pumps, hydrants, and hose should be used to advantage while the fire department lines are being stretched. This can save much important time and effort. To advance lines through passageways, approach should be from the windward side if at all feasible, using two lines in the same direction, preferably one or both being fog.

If the fire is in a hold, while lines are being stretched to extinguish the fire, other lines should be stretched to prevent extension of the fire by heat radiation from the bulkhead. If hatch covers are to be removed, lines with various types of nozzles should be held ready. Access to holds may be by way of ladders and trunk ladders. If advance into the hold is impossible, distributors of the Heffernan type, with six 1-in. outlets operated at high nozzle pressure can be used to darken the fire down. These distributors do a good job when operated about 4 ft below deck and moved about for better coverage by means of a roof rope secured to the male butt of a 3½-in. hose.

Stability. In buildings, most of the water used to extinguish fires flows out again, whereas in ships most of the water is retained within the hull. As a result, the stability of the vessel may be affected. Neglecting the problem of stability can have serious consequences: the vessel may list or capsize. The fire officer can reasonably be expected to recognize the signs that stability is being affected and to know how such a development can be counteracted.

Heel and *list* both refer to the inclination of the vessel to one side or the other: a heel is temporary, a list more permanent. A heel or list, or increased immersion of the hull, can be determined by inspecting the Plimsoll marks. The *Plimsoll mark* (load line) consists of a disk 12 in. in diameter, through which a line 18 in. long is drawn horizontally. Associated with the disk are lines to denote the greatest depth to which a vessel is permitted to be loaded in different seasons and in different circumstances. A Plimsoll mark is painted and cut amidships on each

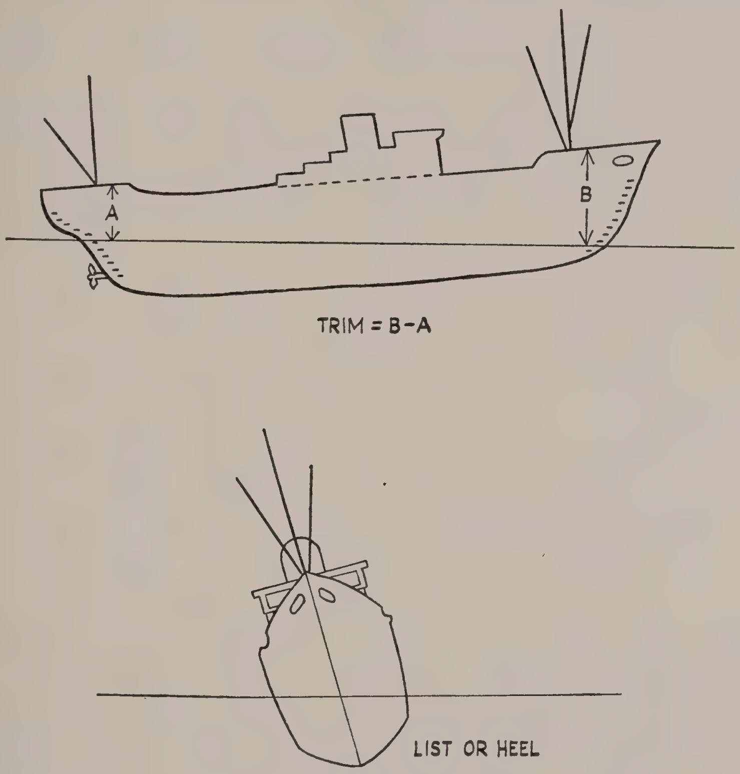

FIG. 6-3. Heel and list.

side of a cargo vessel. By careful observation and comparison of these marks during a fire operation, it is possible to gage the effect of the intake of water or shift of cargo.

The draft of a vessel is the distance from the underside of the keel to the water line when the vessel is upright. This distance may be greater aft than forward. *Trim* is the difference between the draft at the bow and at the stern. Draft marks, in Roman or Arabic numerals 6 in. high and 6 in. apart, are usually painted and cut in or welded at the bow and stern on each side of the hull. Change of trim can be gaged by observing the forward and aft draft marks.

The first step to ensure stability is to contact and consult with the ship's engineering officer about the location and use of the valves controlling the transfer of fuel, flooding compartments to counteract a list, pumping out holds, etc. The counterflooding technique can also be used to correct adverse trim conditions. Other measures to reduce dangerous water accumulation are the use of eductors and oxyacetylene torches.

Ship's officers can determine tons per inch immersion, or how much weight will cause the ship to sink 1 in. at a given water line or to lose *freeboard* (distance from the water line to the top of the deck at side). This information is relevant when much water is being taken aboard. The fire officer must rely heavily on ship's personnel to combat the stability problem.

Required Fire Protection. Fire-protection codes impose the following requirements on passenger-cargo vessels: an efficient fire patrol must be maintained, and in parts inaccessible to patrol a fire-detecting system is

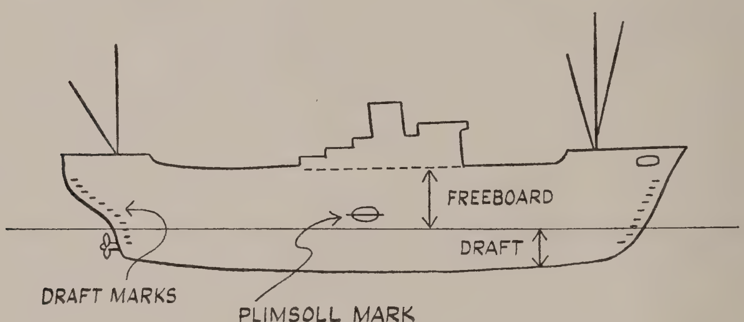

Fig. 6-4. Plimsoll marks.

required; pumps are required to have a capacity adequate to supply at least two effective streams. Two pumps will suffice if the vessel is less than 4,000 tons, and three pumps at least are needed if the vessel is above 4,000 tons [tonnage implies volume as well as weight, 1 ton equaling 100 cu ft; the *net register tonnage* indicates the total volume available for carrying cargo and passengers, and the *gross tonnage* is determined by dividing the total internal volume (capacity in cubic feet) by 100; thus a vessel of 4,000 tons gross tonnage has a total internal volume of 400,000 cu ft, regardless of how the length or other dimensions may differ on various types of ships]; fire mains are required on each deck, with closely located fire plugs and hose; a smothering-gas system that has a capacity equal to at least 30 per cent of the largest hold, or an equivalent extinguishing system, must be provided; extinguishers must be adequate in number and type, with at least two in the machinery space; smoke helmets or breathing apparatus and a safety lamp (two sets) must be available, remotely located from each other.

On vessels over 150 ft in length with sleeping accommodations for passengers, an automatic sprinkler system or an automatic fire-detecting system may be required in the sleeping quarters. In addition, oil-burning vessels must provide (1) the means to direct two powerful streams rapidly and simultaneously into any part of the machinery room, (2) suitable conductors for spraying water on oil without undue disturbance of the surface, and (3) means for discharging foam to a depth of 6 in. in the boiler or machinery room, with the foam control located outside. Where carbon dioxide smothering systems are used, the containers and valves are to be easily accessible and not located where they can be readily cut off from use in the event of a fire. Two extinguishers suitable for use on oil fires shall be provided in the machinery room. One 30-gal foam extinguisher is required for ships that have one boiler room and two if there are two or more boiler rooms. Sand or sawdust impregnated with soda or the equivalent is also required in the machinery room. The amount specified is 10 cu ft, and scoops must be on hand for use.

Fire Protection on the "America." The manner in which these requirements are met is interesting to study. In some cases, the requirements are voluntarily exceeded. The liner "America" illustrates this point. It was originally built as a passenger-cargo ship but was used as a Navy transport during World War II and then reconverted to its original status in November, 1946. It is 723 ft long, with a sports deck equivalent in height to about ten stories above the keel (the lowest lengthwise member of the framework), and carries 1,060 passengers plus more than 600 officers and crew members. The cargo and refrigerator capacity is over 370,000 cu ft. Such a ship requires a huge oil-storage plant and a power-generating station capable of serving a fair-sized city.

An elaborate system is maintained to ensure early detection of fire and early transmission of the alarm. The heart of the entire detection system is the fire station, adjacent to the chart room. Three separate and independent systems at the fire station warn the ship's officer on the bridge at the first outbreak and apprise him of the location. The following well-devised plan of action is then carried out:

1. The officer on the bridge sounds a general fire alarm over a total of ninety-three bells throughout the ship.

2. Immediately following the general alarm, the number of the fire zone is transmitted for the information of those in charge of firefighting strategy. The zone is recognized by the code number given to the forty-eight fire zones and distributed throughout the ship to ensure proper location of the fire.

3. When the alarm switch closes, another switch in the wheelhouse is opened simultaneously. More than 200 fireproof doors close swiftly and silently all over the vessel so as to confine the fire to the area of origin by subdividing horizontal and enclosing vertical channels. However,

these doors can be opened from either side, even by a child, thus eliminating the danger of anyone being trapped by their closing.

4. Watertight doors are closed with hydraulic pressure of 625 lb, sliding fifty-seven heavy steel panels into place and sealing the hull of the "America" into fourteen separate watertight compartments. The purpose is not primarily to aid firefighting operations but rather to ensure the ship's buoyancy (integrity). Clanging gongs warn of the closing so that all persons will stay clear and avoid injury. The doors can be operated manually on both sides of the bulkheads and by remote control on the decks above the water line. The officer in the wheelhouse is instantly informed by an electric diagram if any door fails to operate or if any door is operated by local controls at any time.

5. Ventilating systems generally have to be shut down. Manually controlled dampers shut off what could otherwise be a powerful current of air driven by prevailing winds. These dampers, when closed, reduce the possibility of extension of fire throughout the ship via the ventilating ducts.

6. The local fire department is promptly notified. Many of these steps have been designed for fire operations at sea, but they are also appropriate for use by local fire departments called to fight a fire in a ship tied up to a pier.

The firefighting equipment on the "America" consists of the following: the contents of carbon dioxide cylinders of the 50-lb size can be released through the ¾-in. ducts of the detecting system. Three tons of carbon dioxide are available. There are 230 extinguishers of various types and sizes located in strategic places throughout the vessel. Water mains, 8 in. in diameter and tested to 200 psi, have been installed. A pressure of 60 psi is maintained at all times in these mains. A gage in the fire station, which is always under surveillance, indicates the pressure maintained.

Fire pumps can furnish a total of 3,000 gal per minute. There are two centrifugal fire pumps, each capable of 500 gal per minute, powered by electric motors connected to the ship's power plant and by a diesel-powered emergency generator located high above all habitable decks in the dummy stack, and there is a set of twin pumps driven by steam from the ship's boilers, which are held in immediate reserve. Two pumping units normally used to supply the sanitary systems can also be discharged into the fire main. Hydrants are located so that no part of the ship is a greater distance from the main than the length of a single section of hose. The majority of the 156 hydrants on board have two discharge outlets. Hose, in 50-ft lengths of 2½-in. size with ⅞-in. open nozzles, is attached to each of the 47 hydrants on the exposed decks. Interior hydrants have a 75-ft length of 1½-in. hose with ⅝-in. open nozzles.

There are other steps taken on the "America" to prevent fire, retard its

spread, or prevent panic. Every single piece of drapery in the public rooms and staterooms has been treated with the most advanced methods of fireproofing. Staterooms are sheathed in asbestos. Fire-resisting materials protect public rooms and spaces. Ventilating louvers in stateroom doors have been placed in the lower rather than the higher part in order to retard involvement in fire, smoke, and possibly toxic gases. A public-address system with loud speakers both on the open decks and in the public rooms enables the ship's officers to give instructions in emergencies, to control the movements of passengers and crew, and to prevent panic.

The organization, training, and assignments of personnel have been considered and developed by ship officers with a fire at sea primarily in mind, and the strategy has been comprehensively preplanned. Organization and training are excellent. Each man in the crew knows his exact task in the event of fire. In all parts of the crew's living quarters, as well as in other parts of the ship, station bills are posted, lengthy lists specifying the duties of each of the ship's personnel. On hearing the fire alarm, the members of the deck, engineering, and steward's departments move to fulfill their individual assignments.

The emergency squad consists of thirty-eight men, mainly from the deck force but including specialists from the engineering and steward's departments (electrical engineer, ship's carpenter, ship's plumber, etc.), and forms a highly trained, skilled, and mobile unit, which proceeds to the scene of the fire to aid in firefighting. This squad is equipped with oxygen masks, spray nozzles, and forcible-entry tools. Actually, this response in manpower is greater than that at full first-alarm assignments in most municipalities. In addition, a crewman is assigned to intakes of ventilating inlet ducts to close dampers, to each of the more than 200 fireproof doors, to each of the 57 heavy steel watertight panels, and to each of the 156 hydrants.

During the fifteen days required for a round trip to Europe, at least four fire drills are held. They are carried out very seriously and timed by stop watch, with no excuses permitted. In each drill, every fireproof door is closed and a crewman assigned, every watertight door is closed and a crewman assigned, hose lines are led out from racks, fire pumps are started and water used, and each piece of safety equipment is checked.

Conclusions. The treatment of construction and its effects on fire operations has been fairly extensive, but it is far from complete. Many types of structures have not been touched. The reader can apply the pattern outlined here to other types of structures that may be of particular interest and importance to him.

7

Building Occupancy

General Effects of Occupancy

The nature of an occupancy can definitely complicate the problem of sizing up a fire situation. Human occupancy may create a severe life hazard; or the contents may create difficult fire conditions, such as very heavy smoke and poor visibility.

Human Occupancy. The problems of rescue and all related activities (locating the fire, ventilation, search of premises, removal of occupants, and use of hose lines) are intensified by human occupancy at night clubs, theaters, churches, etc., where the allowable occupancy (maximum legal number that can be accommodated) is so large and of such density as to induce panic in the event of fire or smoke; in hospitals, schools, and institutes for the care of children, the blind, the deaf and dumb, and the elderly, where difficulties are increased by the physical handicaps of occupants; in jails or asylums, where rescuers may have to contend with inmates under restraint or mentally hostile, cope with heavy locked doors, or cut through bars on windows; in multiple-residential structures, particularly those of old, nonfireproof construction, where rescue work is frequently complicated by overcrowding and by language barriers; in residences where children are left alone or where they are assigned to sleep in the upper level of the home. In the former case, parents may be almost criminally negligent; in the latter, parents simply do not realize how hazardous such an arrangement can be. All too often, casualties occur before the fire department arrives.

Contents. Generally speaking, the nature of contents may affect ventilation, use of hose lines, supervision of fire personnel, etc. For example, oils, greases, fats, rubber, wax, tar, and some plastics produce large volumes of smoke, which may be largely unburned vapors. The heat of this type of smoke is low, as is its buoyancy, and visibility is impaired. Such a condition slows down ventilation. Some materials give off gases that are toxic or injurious to the eyes or skin. Burning silks and woolens, for example, give off carbon monoxide and hydrogen cyanide gases; both are toxic, and the latter can be absorbed by the skin. Ammonia is also given off and will injure the eyes, lungs, and damp skin areas. Ventilation is achieved more slowly in such a case because firefighters take time to don appropriate masks and protective clothing.

Where the presence of explosive mixtures or substances is suspected, exterior ventilation measures should be taken to prevent an explosion or to minimize its results. For example, an adequate roof vent will very often prevent a back-draft explosion.

The use of streams may be adversely affected by an excessive quantity of contents and by the manner in which they are stored. Stock may be piled so high that it reduces the effectiveness of sprinklers and streams. Such a situation makes it hazardous for units to advance lines. There is serious delay in establishing control and more than usual water damage.

With certain contents, water will spread the fire. Gasoline, fuel oil, kerosene, and similar materials are lighter than water, will float on top, and thus spread the fire. Calcium carbide with water gives off acetylene gas and may cause an explosion. Some flammable liquids are miscible with water, and unless they can be diluted to a point at which flammability is no longer possible, the fire may spread. Water used improperly in the presence of combustible dusts, such as wood, flour, zinc, or magnesium, may throw them into suspension and develop an explosive mixture. The use of water near acids in carboys, for example, in a wholesale drug occupancy may cause failure of the carboys by sudden chilling or impact of stream, permitting spread of the acids. The resulting release of gases may intensify the fire and abet extension.

Contents in some cases react dangerously with water. Calcium carbide may cause an explosion. Calcium oxide gets hot on contact with water and could conceivably ignite nearby combustible materials. When potassium and sodium nitrates in large quantities are involved, they may fuse in the heat; the application of water may cause extensive scattering of the molten material. Nitrates are soluble in water, and where such solutions come in contact with ordinary combustible material, they may affect it so that it becomes highly explosive when dry. Sodium and potassium liberate hydrogen in contact with water and then ignite the released hydrogen, with the danger of fire and possible explosion. Sodium

and potassium peroxides react vigorously with water and release oxygen plus heat.

These examples are far from complete. Officers are advised to carry reference material on all major pieces of apparatus to facilitate operations where hazardous substances are involved. It is dangerous to depend entirely on memory or the availability of competent advice in such cases.

In operating hose lines, particular care should be exercised if live electrical equipment or unprotected metal structural members are present. Runoff water in puddles may become charged, creating a hazard for the operating forces as well as unnecessary damage. The use of water on highly heated steel or cast-iron structural members may cause them to fail, particularly if they are unprotected.

Steel is used for vertical columns or horizontal beams because of its great strength in tension and compression. At fires, it may buckle and twist out of shape; horizontal beams may expand (see below, Metallurgical Industries), pushing out bearing walls and causing structural collapse. Failure of cast-iron pieces may be sudden and complete; such a happening should be watched for at fires in old commercial nonfireproof buildings, where unprotected vertical cast-iron columns are frequently met (cast iron is seldom used for horizontal supports as it is comparatively inferior in tensile strength). The weaknesses of metal structural members at fires are accentuated when they are unprotected. Protection in the form of adequate fire-resistive materials and assemblies should be provided whenever and wherever practicable.

Effect of Contents on Selection of Extinguishing Agent. Occasionally, water damage is done at fires to extremely valuable or irreplaceable art treasures. If at all possible, a less damaging (but effective) extinguishing agent is used.

Highly absorbent materials, such as rags, paper, or cotton, will readily increase in weight and volume when water is applied. This may result in overloading of floors, distortion of the structure, and ultimately collapse.

A minimum amount of water should be used to extinguish. Fog and wetting agents may be advisable.

Where radioactive materials are present, low-velocity fog is advocated so as not to disturb and possibly expose them.

Where contents are combustible and plentiful, as in a lumberyard, fires are characterized by rapid spread, high temperatures, and a spark-and-ember hazard. To extinguish the main body of fire, heavy-caliber and high-pressure streams are in order. Lighter mobile lines can cover the spark-and-ember hazard.

Molten material in kettles sometimes starts burning if temperature control fails, and the fire may extend to surrounding objects. The ju-

dicious use of fog (both low- and high-velocity, not applied continuously) may cool the contents of the kettle and put out the surrounding fire. The fog cannot possibly get into the kettle, since the water will vaporize at the temperatures present. Consideratioin must be given to the large volumes of steam that will be liberated.

The supervision of fire personnel obviously can become a greater problem where contents complicate fire operations, since unusual and dangerous circumstances may be present.

Effects of Modern Industries

Some modern industries create special problems in firefighting because of certain materials in use or certain circumstances of operation. As examples of these special problems, the following industries will be considered: (1) metallurgical industries, (2) the aviation industry, (3) supermarkets, and (4) industries in which radioactive materials are handled.

Metallurgical Industries. Metals can be classified into the following groups:

1. The alkali group, which includes sodium, potassium, and lithium.
2. The alkali-earth group, which includes barium, strontium, calcium, and magnesium.
3. The iron group, which includes iron, aluminum, chromium, manganese, zinc, cobalt, nickel, and titanium.
4. The heavy-metal group, which includes copper, antimony, tin, tungsten, lead, mercury, platinum, and gold.

The Alkali Group. Metals of this group may cause serious dust explosions, and they have other dangerous characteristics. On contact with water, they release hydrogen, with the possibility of ignition and, in some cases, explosion. Alkali metals are so highly oxidizable that they are generally stored under hydrocarbons. They react spontaneously in the presence of chlorine or sulfur and violently with common extinguishing agents such as water, foam, and carbon tetrachloride. Carbon dioxide will not extinguish a sodium fire. In addition, these metals have low melting points and will readily turn into a molten mass at fires.

In some occupancies (scientific institutions and research foundations as well as many AEC installations), sodium or some other alkali metal may be used as a heat-transfer agent to carry the heat from an atomic pile to water, which is converted to steam and then utilized in standard equipment to create electrical energy. In these circumstances, two types of sodium are used: one, referred to as *primary sodium,* is radioactive and is kept behind the biological shield; the other, *secondary sodium,* is not radioactive but could be involved in an accidental water-sodium ex-

plosion in the boilers. Both types, when exposed to air, burn spontaneously. In addition, both give off sodium oxide, which combines with moisture in the air, on the body, or in the lungs to form sodium hydroxide (lye).

When such material is involved in fire, it is important to remember that only specially prepared commercial dry sand, dry graphite, and dry talc can be used with any degree of success. In addition, persons fighting such fires should be provided with suitable protection. Blankets of glass wool or similar materials have been used to control limited liquid-metal fires.

The Alkali-earth Group. Barium, strontium, and calcium decompose water in their massive state but not with such vigor as to ignite the hydrogen released. These three metals are generally found in the form of alloys, which do not decompose at ordinary temperatures. However, there is danger in the presence of oxidizing agents and strong acids. These metals, like the alkalis, will burn in the presence of carbon dioxide if heated to their ignition temperature.

The alkali-earth metal magnesium merits separate consideration (see also Chap. 3). The increased use of magnesium in pure and alloyed form in industry and in the home increases the frequency with which the problems of magnesium fires must be met.

Magnesium has a great affinity for chlorine and nitrogen. This makes it difficult to provide a suitable extinguishing agent. Magnesium also has a low ignition point and low melting point. Some alloys in a finely divided state will ignite at about 800°F, and finely divided magnesium powder will ignite at temperatures below 900°F; magnesium ribbons and chips or fine shavings can be ignited at about 950°F. Pure magnesium melts at 1202°F and boils at 2043°F. There is some conjecture about temperatures essential for free burning of metals in air. Of course, mass and form are factors (see Chap. 4).

Magnesium scraps and clippings create a fire hazard because they are subject, in the presence of water and oil, to spontaneous ignition. The hazard of explosion and blast damage is also present. Magnesium dust is also explosive and generates high explosive pressures. If, after a fire has started, water contacts a burning mass of magnesium, it may be decomposed with explosive violence. If this occurs in a structure that lacks ventilation facilities adequate to dissipate the sudden pressures, the walls or roof may collapse.

Further dangers occur in industrial installations using magnesium with heat-treating furnaces because toxic sulfur dioxide vapors may be present and because the temperature of the salt baths is close to the ignition point of magnesium, increasing the hazard of fire. Automatic controls are heavily depended on for safety.

When magnesium is burning intensely, the actinic light produced is very harmful to the eyes.

The Iron Group. Metals of the iron group in the massive state are not combustible in the ordinary sense of the word. However, at high temperatures they may be oxidized in some cases, yielding light and heat. In the finely divided state they are more combustible.

Iron and steel are obviously important metals from the viewpoint of the fire service since they are used so extensively in building construction. Cast iron may break when heated and suddenly cooled (as when heated by fire and suddenly cooled by a hose stream). Of the strength of cast iron at 70°F, 76 per cent is retained at 930°F and 42 per cent at 1100°F. The strength of cast steel at 930°F is 57 per cent of its strength at 70°F. Steel expands 8 parts in a million for each degree of rise in temperature. Therefore, when heated to 1000° above normal (that is, to 1070°F), a 100-ft length of steel will expand about 9 in. Such expansion may push out bearing walls and cause collapse of the structure.

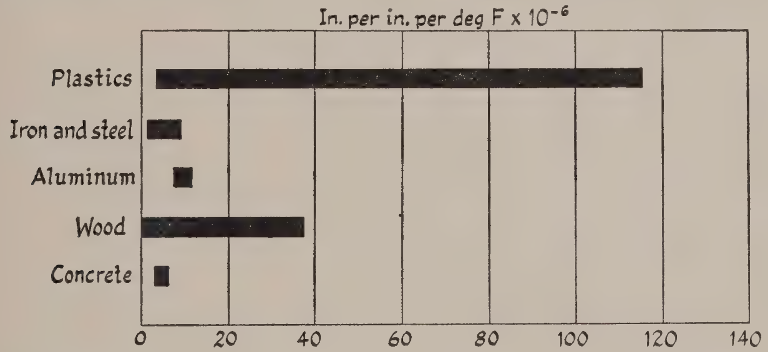

FIG. 7-1. Thermal expansion range for various materials. (*From "The Contemporary Curtain Wall," by William Dudley Hunt, Jr., McGraw-Hill Book Company, Inc., New York,* 1958.)

Titanium is used as a structural metal in atomic reactors on account of its superior radiation-resistance characteristics. There has been a considerable increase in the use of this metal, which is silvery gray in color and resembles carbon steel in appearance. It is as strong as many varieties of steel but only 56 per cent as heavy; it is about six times as strong as unalloyed aluminum and only about 1½ times as heavy. Titanium presents a serious fire hazard during production of the raw sponge, melting of the sponge, and subsequent operations that create fine turnings and chips, which burn rapidly when involved. Combustion can occur in atmosphere other than air; for example, above 1475°F, titanium burns readily and vigorously in atmospheres of pure nitrogen. At red heat (1300°F), it decomposes steam to free hydrogen. A layer of fine titanium

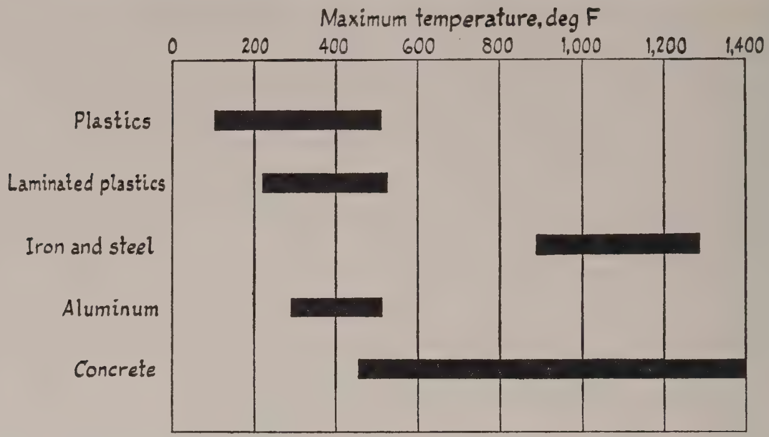

FIG. 7-2. Upper temperature limits for various materials (commonly accepted averages). Ranges for concrete and metals are assumed to be those in which the materials have lost 50 per cent of their original strength. (*From "The Contemporary Curtain Wall," by William Dudley Hunt, Jr., McGraw-Hill Book Company, Inc., New York,* 1958.)

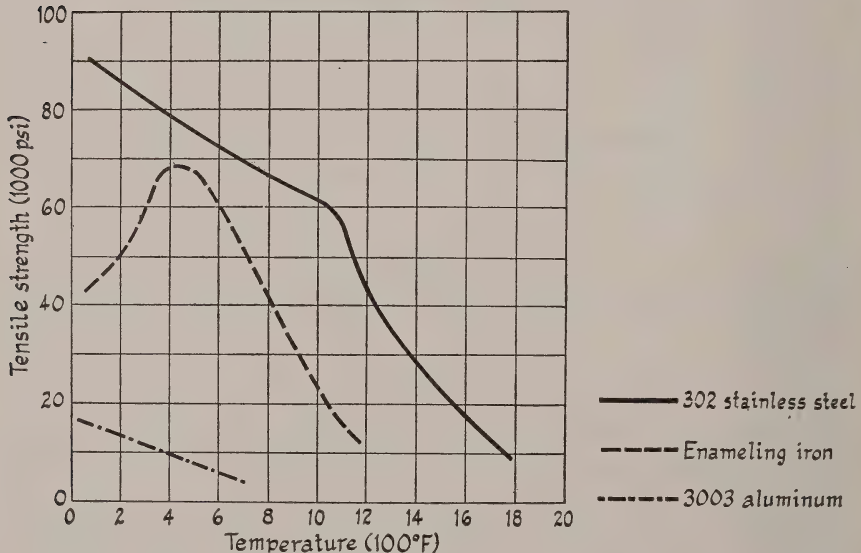

FIG. 7-3. Tensile strengths at elevated temperatures of aluminum, stainless steel, and enameling iron. (*From "The Contemporary Curtain Wall," by William Dudley Hunt, Jr., McGraw-Hill Book Company, Inc., New York,* 1958.)

powder can be ignited in pure carbon dioxide at 1256°F. Fine-powder test samples have ignited in air as a cloud at 896°F. Methods of controlling and extinguishing titanium fires are still experimental. Carbon dioxide and carbon tetrachloride are not effective, and other agents containing water are not recommended. Inert gases such as argon and helium are effective if they can be applied so as virtually to exclude air. There is no complete agreement about methods: some authorities have reported that a coarse water spray successfully put out fire in small piles (10- by 2½-in. triangular section) of crushed titanium sponge and titanium turnings.

Table 7-1. *Dimensional Changes of Materials Caused by* 100°*F Temperature Change*

Material	Approximate coefficient of expansion, in. per in. per deg F $\times 10^{-6}$	Dimensional change, in. — Length of material		
		5 ft	10 ft	15 ft
Aluminum	13.0	0.078	0.156	0.234
Stainless steel	9.6	0.058	0.115	0.173
Carbon steel	7.0	0.042	0.084	0.126
Glass	5.0	0.030	0.060	0.090
Concrete	8.0	0.048	0.096	0.144
Stone	4.0	0.024	0.048	0.072
Reinforced plastic	16.0	0.096	0.194	0.286

Zirconium is also used as a structural metal in atomic reactors because of its superior radiation resistance, and it too will burn rapidly in scrap form. In its pure form this metal has a silvery luster or lustrous crystalline scales and is produced commercially as a dark, gray powder. It is especially hazardous because the dry powder is ignitable at low temperatures by simple friction or static electricity. The powder ignites at 320°F. Dispersed into the air as a cloud, it explodes spontaneously, ignited by the static electric charge generated in the dispersal of the cloud. As a fine powder, it ignites in nitrogen at 986°F and also in carbon dioxide at 1040°F. At high temperatures, it has a great affinity for oxygen and combines rapidly and completely with nitrogen, phosphorus, sulfur, the halogens, and other nonmetals.

Zirconium powder is safer to handle when wet because it is then more difficult to ignite. Once ignited, however, the metal burns violently, decomposes the water, and uses the oxygen released for its own combustion. The steam formed within the burning metal causes a dangerous

scattering. Powder containing from 5 to 10 per cent water is the most dangerous in this respect.

Extinguishment presents a difficult problem except where small amounts are involved. Fire in a comparatively small amount of zirconium may be controlled by applying a large amount of foam very rapidly but without disturbing the powder. Dry sand may also be effective on such fires. In general, methods effective against magnesium fires should also be effective against small zirconium fires. Carbon dioxide, carbon tetrachloride, water, and soda-acid extinguishers are not recommended.

Atomic-fuel Metals. This group includes uranium, plutonium, and thorium. Uranium in finely divided form, such as chips, shavings, or turnings, may ignite spontaneously unless kept under water or oil. Very fine uranium dust will even ignite under water if allowed to accumulate. Fires in burning uranium chips, especially out of doors, can be extinguished by shoveling the involved material into a drum of water. There will be no violent reaction, although some hydrogen gas is liberated. Automatic sprinklers provide satisfactory protection for uranium scrap storage.

Depleted uranium, which remains after uranium 235 has been extracted, is chemically identical with *natural uranium.* Neither presents a nuclear-accident hazard and therefore may be stored in large quantities. Firefighting techniques are the same for both. Finely divided metal may ignite spontaneously, but the solid metal probably will not. Solid uranium is, however, vulnerable to heat from other burning material. Burning uranium reacts violently with carbon tetrachloride.

Enriched uranium is material in which the percentage of the fissionable isotope uranium 235 has been increased. A nuclear accident is possible when enriched uranium burns unless water is used with great care (see below, Industries Using Radioactive Materials).

In cases where air-collecting systems may help recover the extremely valuable material, enriched-uranium fires are allowed to burn out. If the metal burns to the oxide, there is still a possibility of recovery. It is advisable to avoid special extinguishing agents containing salts or graphite since they are likely to prevent the recovery of the enriched uranium.

In plutonium fires, loss of the valuable material is possible. The metal can ignite spontaneously in both finely divided and solid form. When the quantity of metallic plutonium exceeds "always-safe" quantities, a self-sustaining nuclear reaction may result. The extreme toxicity of the oxides generated and dispersed during a plutonium fire is a severe hazard to firefighters and complicates control and extinguishment. Decontamination requires more time, money, and manpower, and hence is a much more expensive process, compared with cleaning up after a small fire in other metals.

Plutonium fires generally burn without visible flame and are characterized by comparatively slow combustion accompanied by intense heat and brilliant white light. The light may be partially masked by an oxide coating over the burning metal surface, but the heat is often sufficient to melt stainless steel: 2500° to 2750°F. These fires are extremely difficult to extinguish and, wherever possible, are handled in closed systems, allowing the metal to burn to an oxide while the very toxic fumes are suppressed in dust-collecting equipment.

Comparatively little is known about reliable methods for extinguishing plutonium fires, but there is definite knowledge about extinguishing agents that should not be used. These include water, foam, soda-acid, carbon tetrachloride, and dry chemical (sodium bicarbonate). Carbon dioxide is also unsatisfactory, and it may significantly increase the dispersal of plutonium oxides.

Met-L-X (sodium chloride), G-1 (graphite), sand, dolomite, and magnesium oxide, all in the form of dry powder or granular material, are considered to be effective against burning plutonium, although they do not in all cases completely extinguish the fire. They do, however, serve the valuable purposes of confining the highly toxic oxides and providing sufficient thermal insulation to expedite handling of the burning plutonium.

The methods used at plutonium fires naturally vary with the amount, form, and location of the metal. Most frequently, "always-safe" quantities of plutonium are handled in sealed hoods operating under negative pressure. In such cases, an effort should be made to isolate the burning metal and cover it with one of the dry extinguishing agents listed above. The covered burning material is then placed in a metal container partially filled with a recommended extinguishing agent so that contact between the plutonium and the container is prevented. If necessary, more extinguishing agent is added before the container is fitted with a loose metal cover. This method prevents melting of the container, provides helpful thermal insulation, and reduces contamination by confining the oxides generated during combustion. In some cases the plutonium may continue to burn under the extinguishant for as long as a day, and complete reduction to the oxide may then occur.

Thorium metal and thorium powder can ignite spontaneously. Thorium is used in so-called breeder reactors. In this type of reaction, thorium converts to uranium 233, a fissionable isotope. Burning thorium can be handled in the same manner as natural uranium.

The Aviation Industry. Plane crashes and attendant fires are increasing in number and severity because the air space over cities is becoming increasingly congested. In the New York metropolitan area, for example, three major airports operate within virtual gliding distance of one another

and together handle more than 1,650 airliners a day, an average of more than one take-off or landing every minute. In addition, other airfields of various kinds and sizes, handling hundreds of aircraft of all types, operate within the 40- by 50-mile metropolitan area. More than 120 aircraft have been simultaneously airborne in this area, and a federal survey indicates that the number will have increased to 350 by 1965. Similar increases can be anticipated in other areas. Flight patterns have become more complicated due to the crossing paths of a greater number of airplanes. When visibility is very poor, planes may be "stacked" on as many as ten separate levels 1,000 ft apart. Each plane successively descends 1,000 ft on radio command after the bottom plane has been sent in for a landing. The possibilities for collision are very great.

The increased use of jet planes, with their high speeds, presents greater problems in air-traffic control to govern blind flying. Since jets require longer landing strips, airfields may encroach on towns, creating a greater life hazard in case of accident.

The increased passenger capacity of modern planes also intensifies the life hazard and the difficulties of rescue operations. Rescue efforts must be made promptly and in the face of high temperatures. Heat-resistant clothing enables rescuers to get much closer to the plane and to operate more effectively. Search for, and removal of, occupants may be made more difficult by the wrecked condition of the plane.

The location of a crash has a great effect on the resulting fire situation. The scene may be remote from aid: the apparatus and equipment that can be summoned may be inadequate. In any event, there will be delay in fire-department arrival, allowing the fire to spread and in all likelihood involve the plane completely. The water supply may consist only of what is carried in booster-pump tanks. Even if the water can be delivered at effectively high pressures, the operation may be handicapped by poor visibility or problems of access.

On the other hand, the location of the crash may create a terrific life hazard, as exemplified by a recent collision over New York City of two large planes. In this accident, 134 persons, mostly passengers, were killed, and if both, instead of only one, aircraft had fallen in populous areas of the city, the number would have been much higher. The fire in the congested area created severe problems in rescue work, protecting exposures, overhauling, and, of course, extinguishing the fire. There were many other problems, such as communications, coordination of fire activities, and coordination with other agencies. It behooves the responsible heads of municipalities to preplan as much as possible the strategy for dealing with disasters involving two or more planes.

The extent of fires that follow plane crashes increases rapidly, due mainly to the large amount of flammable fuel carried. Leakage due to

the crash may involve an area larger than that of the plane. Almost invariably, these fires necessitate the use of special equipment and apparatus to provide high-pressure fog or foam, chemical powder, or carbon dioxide streams. Using the downwash of a hovering helicopter to "keep the lid" on such fires may prove helpful.

The chances for air collision and fire are increased by the use of helicopters to transport passengers and by the increasing attention to rockets, which use products that have high flame temperatures (hydrogen plus fluorine at 4500°C and cyanogen plus oxygen at 4700°C). Commercial aviation hazards are magnified when planes with large passenger lists are allowed to take off in conditions of poor visibility and low ceiling (an airplane with more than 100 persons aboard recently crashed and burned when taking off with about a 300-ft ceiling).

Supermarkets. Supermarkets have developed considerably in number and size during recent years. There are fire hazards of defective heating equipment, frayed wiring, conditions conducive to power failure, and improper disposal of combustible debris; in addition, there are hazards related to human carelessness or disregard for recommended practices in fire prevention or protection, for example, smoking in prohibited areas or storing material in such a way that sprinkler heads cannot operate effectively.

An interior attack on a supermarket fire may be ineffective for several reasons. The extent of the fire is apt to be great since there is a plentiful supply of combustible fuel on hand and areas are open and spacious, abetting the spread of the fire and the development of high temperature. Supermarkets are often located in places remote from firehouses, assignments are smaller than for more congested areas, and water mains are smaller and hydrants more distant from each other. Thus, fires will be more extensive when fire units do arrive, and only a limited attack can be initiated by the small assignment. Two or even three hose streams may be required to advance successfully in a solid front because of the width of such stores and the consequent danger of being outflanked by the fire. By the time lines adequate for such a maneuver are ready, an interior operation may be out of the question because of heavy involvement. The operation may have to be attempted without adequate roof or side ventilation. If the wide roof span is heavily involved, roof ventilation may be too dangerous and inadvisable unless rescue work can be aided thereby. Some supermarkets have solid exterior walls without windows or doors, and in such cases horizontal ventilation is practically nil; as a result, interior operations will be severely handicapped. Cellars, if present, can complicate matters tremendously.

Blank walls often delay discovery of fire at night and transmission of the alarm. Alarm boxes are fewer in some supermarket areas.

The presence of numerous obstacles during business hours—parked cars in parking areas, restricted means of ingress, aisles blocked by shopping carts—hinders an interior operation, the efficiency of which is so dependent upon prompt stretching and advance of hose lines. A serious life hazard may necessitate concentration on rescue work to such an extent that the fire will spread and make interior operations increasingly difficult, if not impossible.

An exterior attack is also frequently ineffective. The circumstances that rule out interior operations abet more complete involvement of the structure and also make the exterior attack more difficult. It is generally impossible to hit the fire with lines from outside the building since the roof may not have been opened up. If openings were made to assist rescue work, they may have been limited in extent. At any rate, they would not be the deciding factors in making outside lines directed over the roof effective. Blank walls add to the difficulty of reaching the fire with an exterior line. The usual construction of supermarkets results in a large area free of columns or partitions. Spans of 100 ft are not uncommon. Trusses are of wood or unprotected steel, and failure of one or more trusses will cause collapse of a sizable portion of the roof, which often happens owing to the ineffectiveness of the usual exterior fire operation.

Covering the life hazard in supermarket fires can be a difficult problem. A large number of customers may be on hand, the great majority of whom are women and children. Turnstiles permit entry but may block egress. Some checking-out counters may be chained off. Restricted egress, wheeled shopping carts in aisles or near exits, large amounts of combustible material in the form of stock or paper signs or banners strung across the sales area add up to panic and a serious life hazard in the event of fire. Rescue work will be impeded also by the probable absence of helpful ventilation and the delay in stretching hand lines.

As at all fires where a life hazard to occupants exists, the initial lines (one or more, as required) are stretched to operate as quickly as possible between the fire and the occupants or between the fire and the means of egress. In placing such lines, however, care should be taken to avoid interfering with the escape of the occupants. Accordingly, it may be feasible for the fire department to use a rear entry. In addition, of course, roof ventilation should be attempted to retard horizontal spread (by localizing the fire) and to draw the heat and smoke away from the sections being vacated (Chaps. 10 and 11).

At small fires with no life hazard, usual tactics may be successfully resorted to: (1) venting vertically and horizontally as effectively as possible; (2) forcing entry in the manner and place that best facilitates the operation, for example, at the rear if the fire is in that area; (3) operating

the lines to achieve extinguishment while at the same time minimizing the possibility of extension. This means using the lines to drive the fire and heat out of the store and not into it.

If the fire is extensive with no life hazard, the commanding officer should be guided by the cardinal principle that firefighters are not to be unnecessarily jeopardized to save property. Reasonable risks are always in order, of course. Putting men to work on the roof of a heavily involved supermarket may exceed a reasonable risk. To minimize such a hazard, it is suggested that a small percentage of the roof area (5 per cent) be provided with plastic skylights that will burn away at temperatures of 800 to 900°F. This would result in automatic ventilation and localizing the fire in its early stages, thereby making a successful interior attack more likely. When an interior attack is inadvisable, lines should be set up to prevent spread of fire to nearby structures (unlikely in the case of suburban supermarkets) while other heavy lines operate on the fire structure until hand lines can approach to finish up the job.

Industries Using Radioactive Materials. The hazards of radioactivity have been publicized mainly in connection with the threat of nuclear warfare (Chap. 1). There is also a more common hazard because radioactive materials have become relatively inexpensive to produce and are increasingly available for use in more and more peacetime industries. Today, these materials can be encountered in universities, industrial laboratories and plants, research laboratories, doctors' offices, hospitals, atomic-power plants, and transportation facilities. Atomic-powered submarines are now a reality and a forerunner of what can be expected in future transportation by ocean liner, aircraft, truck, and automobiles. Much remains to be learned about radioactivity and its dangers by the scientific professions in general and by the fire service in particular.

The following topics are discussed: (1) the nature of radiation, (2) radiation terminology, (3) the more common radioactive isotopes, (4) instruments and dosimetry, (5) transportation accidents involving radioactivity, (6) occupancies with radiation machinery, (7) warning signs, and (8) why radioactivity presents a hazard to the fire service.

The Nature of Radiation. Radioactivity may be defined as the spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nuclei of an unstable, and therefore radioactive, isotope. Isotopes are forms of the same element that have identical chemical properties but different atomic mass (due to the different number of neutrons in their nuclei) and different nuclear properties, for example, radioactivity and fission. Not all isotopes are radioactive. For example, hydrogen has three isotopes, with atomic mass 1 (hydrogen), 2 (deuterium), and 3 (tritium). The first two are stable and hence not radioactive; the third is unstable and radioactive.

As a result of this spontaneous emission, the isotope is converted, or decays, into an isotope of a different element, which may or may not also be unstable. For example, the first step in the decay process of the uranium 238 atom is the emission of an alpha particle. Originally, this atom had 92 protons and 146 neutrons. After emission of the alpha particle, thorium 234, with its 90 protons and 144 neutrons, remains (the alpha particle consists of 2 protons and 2 neutrons). Thorium 234 is radioactive; hence, the decay process continues to form protactinium 234 and then uranium 234. The nuclei of some elements may have the same mass but a different ratio of neutrons to protons. It is because of this difference that thorium 234, with 90 protons and 144 neutrons, emits a beta particle and uranium 234, with 92 protons and 142 neutrons, emits an alpha particle.

The final step in the decay of the uranium 238 atom is conversion of polonium 210 to lead 206, which is stable and not radioactive.

Gamma radiation originates when the discharge of an alpha or beta particle does not take away sufficient energy to leave the nucleus in a contented, or stable, state. The remaining undesirable energy is given off as gamma radiation.

It is not possible to predict when disintegration will take place if only one atom is involved. However, if many atoms are involved, a statistical determination can be made that half the atoms will disintegrate in a given period of time. This is the so-called half-life of radioactive materials, and it may range from a fraction of a second up to thousands of years. The shorter the half-life, the more highly radioactive the material is. Fortunately, isotopes with very short half-lives are not widely used because they decay so rapidly, and there is little likelihood of the fire service encountering such materials.

The use of radioisotopes is based on the penetrating radiations that are emitted, which allow their location and movement to be traced with considerable precision. Radioisotopes function principally as "tracers." In this capacity, they are used in science, medicine, engineering, industry, and agriculture to show such things as how fertilizers move through the roots of plants and through the stem and leaves, how food is taken into the body and how it eventually gets into the tissues, and how certain components operate in an industrial process. Expanded use of radioisotopes can be anticipated: recently the Atomic Energy Commission estimated that in industry alone savings of half a billion dollars yearly already have been gained through use of isotopes. It is fortunate that fantastically small amounts of isotopes will suffice for tracing, since the potential hazard is thereby reduced.

Radiation Terminology. The standard terms for comparing radiation effects include roentgen, rad, RBE, and rem.

The *roentgen* measures only gamma (or X) radiation in the air. It must always be associated with a unit of time and is generally expressed as roentgens per hour.

*Table 7-2. Decay of a Uranium Atom**

Element and atomic weight	Type of radiation emitted	Number of	
		Protons	Neutrons
Uranium 238	Alpha particle	92	146
		−2	−2
Thorium 234	Beta particle	90	144
		+1	−1
Protactinium 234	Beta particle	91	143
		+1	−1
Uranium 234	Alpha particle	92	142
		−2	−2
Thorium 230	Alpha particle	90	140
		−2	−2
Radium 226	Alpha particle	88	138
		−2	−2
Radon 222	Alpha particle	86	136
		−2	−2
Polonium 218	Alpha particle	84	134
		−2	−2
Lead 214	Beta particle	82	132
		+1	−1
Bismuth 214	Beta particle	83	131
		+1	−1
Polonium 214	Alpha particle	84	130
		−2	−2
Lead 210	Beta particle	82	128
		+1	−1
Bismuth 210	Beta particle	83	127
		+1	−1
Polonium 210	Alpha particle	84	126
		−2	−2
Lead 206	Stable atom	82	124

* From *Living with Radiation*, Francis L. Brannigan, U.S. Atomic Energy Commission, Government Printing Office, Washington 5, D.C., 1959.

The *rad* measures the absorbed dose of any type of radiation. A rad of one type of radiation may have more effect on the human body than a rad of another type. This difference is expressed by the *RBE* (relative biological effectiveness). For example, the RBE of gamma radiation is 1, whereas that of some alpha radiation is 20. This means that 1 rad of

alpha radiation can have approximately twenty times the effect of 1 rad of gamma radiation.

The *rem* (roentgen equivalent man) is a measure of the effect of radiation in the body. It is the unit of radiation dose that makes it possible to express all types of radiation exposures in one term. A dose in roentgen equivalents man is equal to the dose in rads multiplied by the relative biological effectiveness of the type of radiation involved.

Amounts of radioactive material are measured in *curies, millicuries* (one-thousandth of a curie), and even *microcuries* (one-millionth of a curie). A curie is that amount of radioactive material which is disintegrating at the rate of 37 billion atoms per second. The curie bears no relationship to the weight of the material involved. If a material is very slightly radioactive, several thousand pounds might be required to give 1 curie of radioactivity; if it is very highly radioactive, a fraction of an ounce might give 1 curie of radioactivity. For example, 1 curie of cobalt 60 weighs 880 micrograms, but 1 curie of thorium 232 weighs 10 tons.

The curie does not measure radiation hazard; it simply indicates how many disintegrations are taking place every second. The hazard depends upon the quantity and type of radiation emitted.

The More Common Radioactive Isotopes. Isotopes of sodium, cobalt, iridium, potassium, iodine, iron, and gold are used. Sodium 24 gives the most roentgens per curie at 1 ft, but it is used only in highly specialized situations because of its very short half-life. Cobalt 60 is a popular source of gamma radiation because it gives the most roentgens (except sodium 24) among the isotopes readily available. Other isotopes give off comparatively less than half the number of roentgens given off by cobalt 60. Iridium 192, potassium 42, iodine 131, iron 59, and gold 198 give off, respectively, 5.5, 6.84, 2.7, 6.8, and 2.7 roentgens per hour at 1 ft per curie. Atomic piles, cyclotrons, betatrons, and similar machines make it possible to radioactivate almost anything (materials made radioactive in this way are called *by-product radioisotopes*). Therefore, the fire service can expect to meet radioactive materials in many other forms than those specified above.

A fireman opening the roof about 10 ft above the radioactive source of 100 curies of cobalt 60 will be subjected to a radiation level of 15 roentgens per hour, since 1 curie of cobalt 60 gives off 15 roentgens per hour at 1 ft from the source. The 100 curies will give off 1,500 roentgens per hour at 1 ft, but by the law of inverse squares the roentgens per hour received at 10 ft will be 100 times less than that at 1 ft, or 15. If the man on the roof takes 10 minutes to do his job, his exposure will be about 2.5 ($\frac{1}{6}$ of 15) roentgens. The amount of exposure to which men should be subjected depends to a large extent upon the objective sought; if the situation is urgent, greater risks will be taken; if it is not, minimum risk

should be taken. Knowledge of the biological effects of gamma radiation is essential.

Fortunately, the very high-level multicurie sources require massive shielding and special remote control for normal handling. They are invariably installed in facilities built specifically for this purpose and in most cases are built into the ground. When in use, the source is raised out of the ground into a structure. In the event of fire, a heavy-duty fusible link melts and automatically lowers the source back into the shield; then there is no radiation problem at all. In many occupancies where medical work and research is carried on, the amount of radioactive material on hand is so small that the hazard is comparatively insignificant; of course, it cannot be disregarded. Trained personnel in such occupancies should make certain that radioactive sources are restored to their shield in the event of fire or, if necessary and possible, moved to a place of safety. Information on this point should be relayed to the responding firefighters.

Instruments and Dosimetry. Monitoring devices include radiation-detection instruments and devices to measure the radiation exposure of individuals. The best-known radiation-detection instrument is the *geiger counter,* a gas-filled electrical device that detects the presence of radioactivity by counting the formation of ions. It is essentially a low-level instrument, since the maximum reading on most geiger counters is 40 or 50 milliroentgens per hour (a milliroentgen is one-thousandth of a roentgen). Many register both gamma and beta radiation. By closing a shield that covers the Geiger-Müller tube, beta radiation, which cannot penetrate the shield, is screened out and only the gamma radiation gets through. Beta radiation is then computed by taking the open-window reading (beta and gamma) and subtracting the closed-window reading (gamma only).

Ionization chambers, roughly similar to geiger counters and used in civil defense, can read higher levels of beta and gamma radiation, as high as 500 roentgens per hour.

The *scintillation counter* is a very precise radiation-measuring instrument that will detect minute quantities of gamma radioactivity; it counts atomic particles by means of tiny flashes of light (scintillations) produced when the particles strike certain crystals.

Alpha radiation, with its very short range in air and little or no penetrating ability, must be detected on special *alpha-measuring meters,* whose measuring area must be brought directly to the contaminated surface. The surface must be checked thoroughly to detect the contamination. If a surface is irregular and the flat detecting part of the meter cannot be brought to bear, a piece of cloth or tissue is used to wipe a measured area of the surface. This paper or tissue is then checked

to estimate the contamination level, which is generally stated as so many disintegrations per minute per 100 square centimeters (sq cm) of surface. The same wiping technique may also be used for beta- or gamma-contaminated surfaces to ascertain how much of the contamination is removable or fixed to the surface.

Radiation detectors are, in effect, rate meters, since they measure the rate of radiation received by the instrument at a particular time. When removed from the radiation field, they show no reading and past readings will not be reflected.

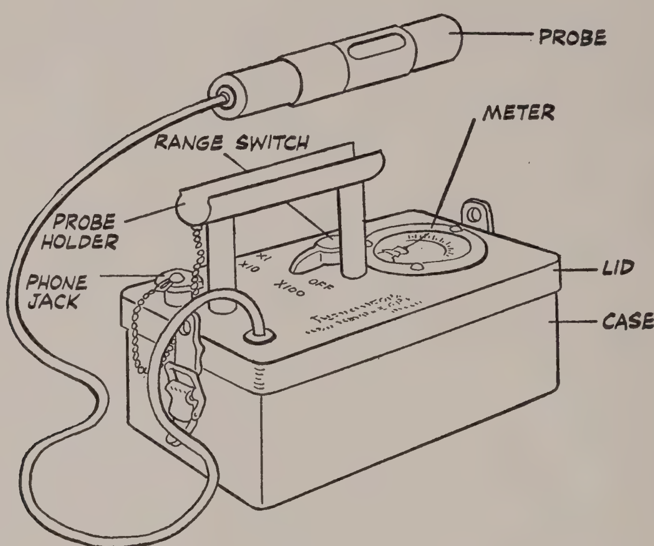

FIG. 7-4. The geiger counter.

Devices designed to measure the accumulated radiation exposure of individuals are of two types: film badges and pencil dosimeters. *Film badges* are bits of dental X-ray film worn in special holders; they provide a permanent record of radiation exposure, but not an immediate one, since time is required to develop the film. A *pencil dosimeter* is a device that records the radiation received from zero to the limit of the scale. Some dosimeters can be read directly by holding them up to the light; others must be read in a special reading device. These devices must be worn at all times when a person is in a radiation area; when not being worn, they should be protected from radiation exposure.

These instruments serve little purpose unless they have been selected by informed persons, since developments in this field are rapid. In addition, they require skilled maintenance and calibration for effective

use. Every branch of the fire service should set up a program, if one is not already in existence, to ensure that appropriate instruments will be available and in good operating condition when needed.

Transportation Accidents Involving Radioactivity. The transportation of radioactive materials and atomic weapons presents serious problems if an accident occurs, some of which apply to all transportation accidents and others of which derive from the nature of radioactivity.

The location of a transportation accident is unpredictable. This minimizes the important advantages that can be gained by preplanning. The problems can be anticipated only in a most general way compared with those in a static industrial situation. An accident may occur in a location that creates a severe life hazard, for example, in the vicinity of an occupied church or theater. It may cause a severe exposure fire hazard depending on the presence of vulnerable structures and the direction of the prevailing wind. It may occur in an area where the fire service is inadequately equipped to handle it or where the water supply is very poor. The transient radiation hazard may be associated with ships, planes, trains, trucks, transit sheds, truck depots, express depots, or transit warehouses. The individual problem may have complex aspects.

When radioactive materials are involved in transportation accidents, there is always the danger of external radiation to the surroundings. Protection against external radiation should be fully utilized; it depends on a combination of distance, time, and shielding. To be effective, these factors must be used in the proper combination.

Distance is an important protection because the radiation intensity varies inversely as the square of the distance. Therefore, if the radiation rate 1 ft from the source is 1,000 roentgens equivalent man (rem) per hour, at 10 ft it will be 100 times less, or 10 rem per hour. This is the variation that can be expected in the immediate vicinity of radiation sources used in industry for penetrating radiation, because such sources are generally quite small in size. Where the source is large, such as the side of a reactor that covers a considerable area or such as might be the case if the radioactive material were dispersed, the inverse-square law does not apply until the distances involved are large in relation to the size of the source. To utilize the factor of distance in a transportation accident, the fire should be fought from upwind, thereby increasing the range of the stream of extinguishing agent and making possible an attack from maximum distance. A solid stream designed to break into a spray at the fire area would be effective and some fog streams would also suffice.

The protection of time should be used to keep single and overall exposures of personnel to a minimum. At ordinary fires, in which radio-

activity is not a factor, officers know by experience when men should be relieved because of existing heat and smoke conditions. If conditions are severe, relief should be provided more often. Where radiation is involved, the officer may not be as qualified to know when relief is needed. Special technical advisors may have to be called upon.

The most effective shielding protection from radioactivity is the preservation of the original shielding container, if that is possible.

To fight effectively a fire involving radioactive material, it is important to have some information about the material. The personnel in charge of

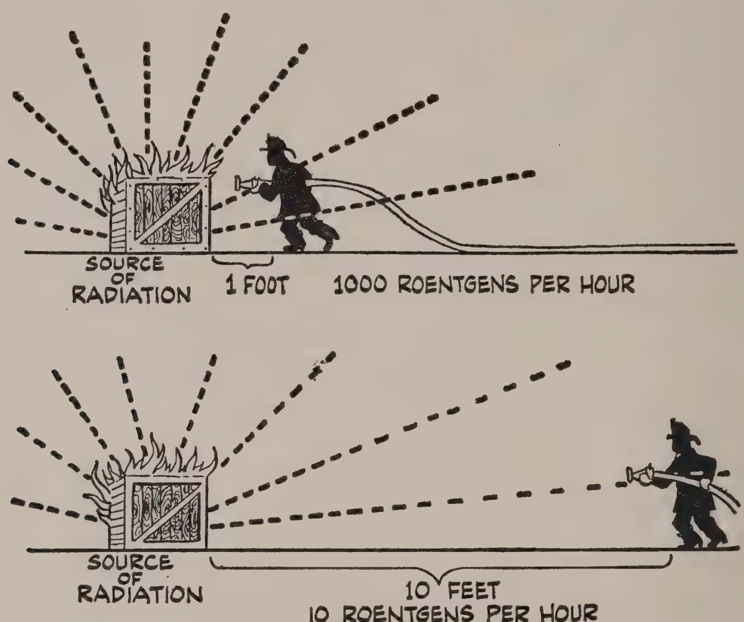

FIG. 7-5. Effects of distance on radiation intensity.

transporting it may have been killed in the accident, and there may be no information on the contents and their nature except for required ICC red or blue labels (see below, Warning Signs). This is a serious situation if monitoring devices are not on hand or if fire personnel are not properly trained in their use. The radioactive materials being shipped may range from a tiny fraction of a curie of a short-half-life isotope to literally millions of curies of mixed fission products in the form of spent-fuel elements taken from reactors.

Water may react violently with some radioactive materials. Hence, it is important to find out, if possible, the chemical nature of the material (flammable, soluble, or liquid) as well as its physical state (solid,

powder, or liquid) so that the most effective extinguishing agent can be selected and used with the least risk of worsening the radiation hazard.

When it is necessary to use water as the extinguishing agent, it is important to keep in mind that the water may be radioactively contaminated even though it is not made radioactive. Therefore, it is highly desirable to extinguish with a minimum amount of water (preferably in the form of low-velocity fog) and to confine the contamination as closely as possible to the point of origin. Standard fire-service salvage techniques should be used to confine the water close to the fire. As the water drains away, radioactive materials may be deposited and contamination may become widespread, even affecting drinking-water supplies.

The problem of contamination as a consequence of these fires is a very serious one and usually requires aid or advice from specially trained persons. In addition to contamination of the water used to extinguish the fire, contamination may occur when materials involved in the fire are reduced to ashes and blow around the area. In this connection, it must be remembered that radioactivity is unaffected by chemical change by fire. For example, radioactive carbon will burn just as ordinary carbon burns, with the important exception that the resulting carbon monoxide, carbon dioxide, and smoke will be radioactively contaminated.

If it is necessary to carry out an emergency operation in a contaminated area, personnel should adapt their clothing to prevent the entry of dust. Such a precaution is essential to minimize the possibility of "beta burns" in the event of direct skin contact. It should be remembered, of course, that clothing offers virtually no protection against gamma radiation.

For dry operations, heavy pants and shoes are recommended, as well as cotton or canvas work gloves and a tight-fitting cap. In dusty areas it is advisable to tie the bottom of the pants and the ends of the sleeves (over the gloves) to prevent entry of contaminated material. A scarf around the neck also helps. It is advisable to avoid inhaling dust, and consequently a self-contained mask should be worn until it is determined that no airborne hazard exists. [Self-contained masks are oxygen and air-demand masks or oxygen-generating masks. Such masks provide a man with his own independent air supply and prevent him from breathing the contaminated air (see Chap. 13).]

For wet emergency or decontamination operations, water-repellent clothing, rubber boots, and rubber gloves are required. These can be cleaned with a stream of water and may be used several times, provided there are no breaks or tears. In addition to wearing the recommended protective clothing and equipment, personnel must be thoroughly checked for contamination after operations are concluded. Careful decontamination of apparatus, equipment, clothing, and persons is always in order. An unusually thorough shower and washing is recom-

mended, with particular attention to those parts of the body that may have caught radioactive material, such as the hair, under the fingernails, and the crevices of the skin, especially around the face and ears.

At times a radiation survey of the area may be necessary. In such a case, technically qualified assistance must be obtained. In many states and municipalities, such aid is available from local agencies; it is also available through the AEC Radiological Assistance Plan. The assistance consists of a team of (1) persons trained and equipped to evaluate radiation hazards and recommend measures for control and (2) medical personnel who may be called upon to advise in the treatment of injuries believed to be contaminated by, or to have been caused by, exposure to radiation or radioactive material. If necessary to save life or to minimize injury, and if no other help is available, AEC personnel will themselves perform rescue work.

The AEC has designated eight of its twelve operations offices as regional offices for its Radiological Assistance Plan. The offices have the direct responsibility of providing appropriate AEC assistance upon request, when radiological accidents occur within their respective regions. The AEC team dispatched to the scene to preserve or recover the radioactive material or to assist in operations is under the direction of the regional operations office. If further AEC assistance is needed, the regional operations office will request it from the appropriate operations office or from the AEC–DOD (Department of Defense) Joint Nuclear Accident Coordinating Center. Appropriate AEC Washington headquarters divisions and operations offices are responsible for disseminating information about the Radiological Assistance Plan. The office of the general manager in Washington is responsible for maintaining in readiness a radiological incident center, which may be activated by appropriate headquarters division directors or by the general manager.

The dangers of shipping radioactive materials are modified by regulations (currently being revised) of the Interstate Commerce Commission, which specify the amount of radioactive material permitted to be shipped in a single container, the permitted radiation level at the surface of the container and at a distance of 1 meter (39 in.) from the center, and the assembly of a number of packages of external-radiation emitters that individually might be of low hazard but collectively might build up a high radiation level if assembled in one location. Other ICC limitations provide that not more than 2 curies of radium, polonium, or other members of the radium family or 2.7 curies of other radioactive materials may be packed in one shipping container. The exception to this limitation is a "specification container" for shipping up to 300 curies of solid cesium 137, cobalt 60, and iridium 192. The highest radiation reading on any accessible surface on the outside of this container must not

exceed 200 milliroentgens per hour of gamma radiation, and the radiation level at 1 meter from the center of the container must not exceed 10 milliroentgens per hour of gamma radiation. Changes in ICC regulations are being contemplated, however.

Occupancies with Radiation Machinery. Radiation machinery includes X-ray machines, cyclotrons, linear accelerators, and betatrons. Fires in such occupancies are complicated by the following factors: a high level of radiation is given off by the machine while it is operating; there may be large quantities of cooling oil present, either in the machinery or in associated electrical transformers; high-energy electrical equipment is present—a cyclotron produces energies of the order of several million volts, the particles to which this energy is imparted having energies of several million electron volts (Mev), and the bevatron accelerator produces particles of a billion electron volts (Bev) energy; a radioactive target is located deep within the machine itself; large quantities of paraffin may be used for shielding, and the vapors given off when it is subjected to heat have a low autoignition point; ventilation may be difficult due to solid and windowless construction in some cases; interior attack may be delayed until radiation is stopped or reduced; many cyclotrons are located in rural areas, and the fire-service response may be limited.

Preplanning is emphasized so that unusual developments may be anticipated, adequate countermeasures decided upon in advance, and maximum coordination achieved between fire-service personnel and appropriate technicians. Preplanning is also indicated because the contents of these occupancies are unusually valuable. Determined, well-calculated efforts to extinguish the fire are required.

Supervision of fire personnel to reduce or eliminate the life hazard is very difficult when these occupancies take fire. All electric power must be shut down promptly to eliminate the hazards of electrocution and to stop the generation of radiation by the machine. Total-flooding carbon dioxide systems should be used if they are available. If they are not satisfactory, fog (low velocity, preferably) or foam may suffice. If entry with fog lines is necessary, overhead cranes should be utilized if available to remove ceiling sections and provide helpful ventilation.

After the fire is extinguished, technical help may be required to retrieve the radioactive target deep within the machine so that it will not present a life hazard during the overhauling phase. Other radioactive materials may be present, necessitating a survey by trained persons.

The fire hazard is not the same in all cyclotrons. Some are water-cooled and some are oil-cooled. Water-cooled machines present few oil-fire hazards, since the amount of oil on hand is generally inconsequential, and many fires can be readily extinguished by dry-chemical or carbon

dioxide extinguishers. In oil-cooled cyclotrons, there is a much greater possibility of a serious class B fire, and smoke damage results because the oils are heavily sulfur-bearing. The sulfur and oil smoke hydrolyze the water in the air to form sulfuric acid, which when deposited on electrical contacts, renders them useless and makes it necessary to tear down all the equipment and rebuild it before power is restored.

Warning Signs. A purple-on-yellow propeller sign indicates a radiation hazard in an occupancy. Precautions to be taken are stipulated on the lower part of the sign, as indicated in Fig. 7-6. Where radioactive

FIG. 7-6. Sign indicating presence of radioactive material.

materials are being transported, their presence is indicated by ICC red or blue radiation labels.

The blue label (Fig. 7-8) indicates that the materials in transit present a radiation hazard only if the package is ruptured. The red label (Fig. 7-7) indicates that the materials present an external hazard from gamma rays or neutron emitters. It also indicates principal radioactive content, the activity of the contents, and the number of radiation units in each package. A radiation unit is defined as one milliroentgen per hour at a distance of one meter from the center of the container, and ICC regulations prescribe that not more than 40 units shall be loaded in one aircraft or held at one point or location. Trucks carrying any amount of "red-label" material must be placarded on each side and in the rear with a sign reading "Dangerous—Radioactive Materials."

Hazard of Radioactivity. Radioisotopes make the air electrically conductive, and the resultant accumulation of static electricity is a serious danger where explosive vapor-air concentrations exist. The emission of alpha and beta particles and gamma rays may cause harmful biological effects.

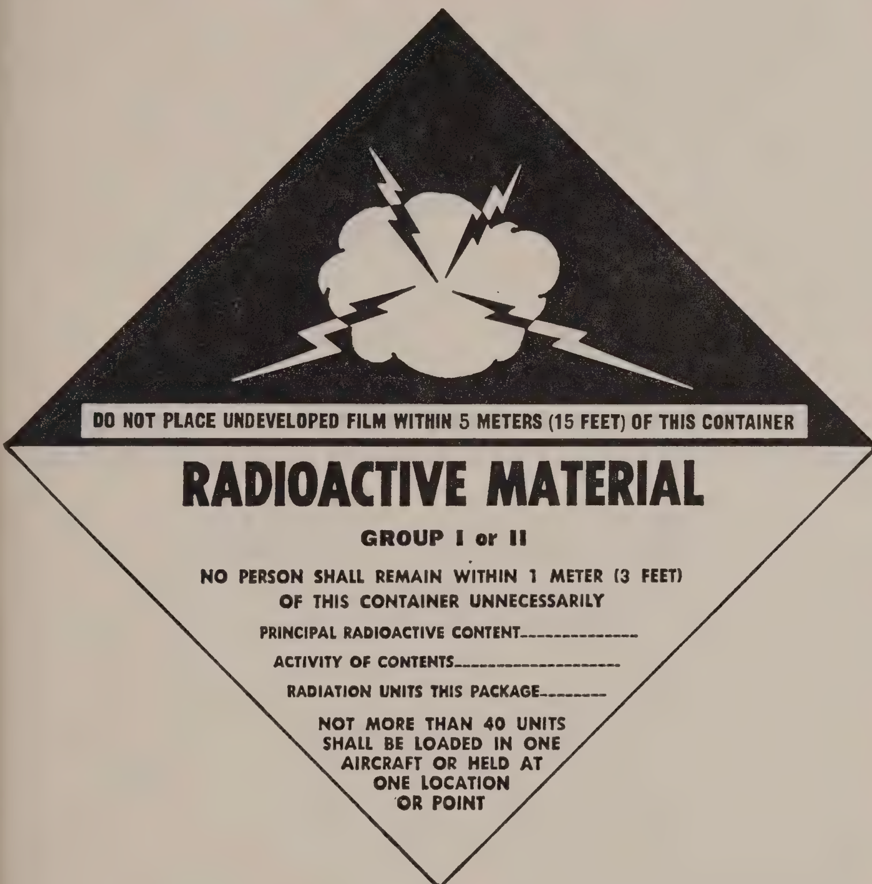

FIG. 7-7. The ICC red label.

An alpha particle is identical with the nucleus of the element helium. When it has lost most of its (kinetic) energy, it captures two electrons and becomes a harmless neutral helium atom. It is neutral because the two negatively charged electrons are matched by two positively charged protons. The range of an alpha particle depends upon its initial energy, but even those from plutonium, which have fairly high energy, have an average range of just over 1 in. in air; in more dense media, such as

water or body tissue, the range is much less. These particles can be stopped by a sheet of paper, and they are unable to penetrate even the outer layer of the skin (epidermis).

The great danger from alpha particles occurs when such elements as uranium or plutonium enter the body through the lungs, the digestive system, or breaks in the skin. The ionization caused by alpha particles

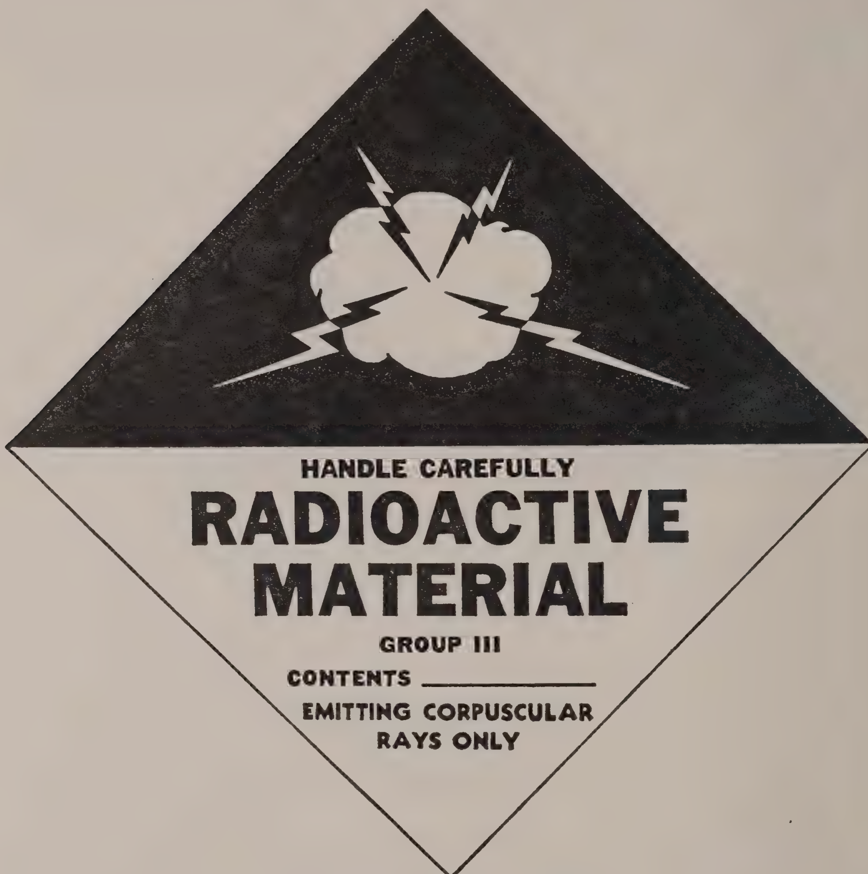

FIG. 7-8. The ICC blue label.

from these elements may cause severe tissue, bone, or organ damage. Plutonium, for example, preferentially concentrates in bone, where it may cause serious harm by prolonged action (plutonium 239 has a long radioactive half-life, 24,000 years, as well as a long biological half-life, over 100 years), and its amount and activity decrease at a very slow rate).

Beta particles are charged particles of very small mass emitted spontaneously from the nuclei of certain radioactive elements, and like alpha

particles, they are able to cause direct ionization as they pass through matter. But beta particles dissipate their energy less rapidly than alpha particles and so have a greater range in air and other media; many emitted from the fission products in a nuclear explosion traverse a distance of 10 ft (or more) in the air before they are absorbed. However, beta particles are easily deflected in their course, and so their effective range is often less.

Injury to the body from beta particles can arise in two ways after a nuclear explosion: most, if not all, of the fission fragments emit (negative) beta particles, and if they come into contact with the skin and remain for an appreciable time, "beta burns" will result. In addition, if the fallout area is extensive, the whole surface of the body will be exposed to beta particles coming from all directions. Clothing will attenuate this radiation to a considerable extent, but if outer layers of the skin receive a large dose, serious burns may result.

Gamma rays are electromagnetic radiations of high energy, originating in atomic nuclei and accompanying many nuclear reactions, for example, fission, radioactive decay, and neutron capture. Physically, gamma rays are identical with X-rays of high energy, the only essential difference being that the X-rays do not originate from atomic nuclei. Gamma rays are the most common form of radiation and the most penetrating: they have the same effects as X-rays. A dose of 25 roentgens of total body exposure within 24 hours produces no detectable clinical effects, but larger doses have increasingly more serious consequences; an exposure of 450 roentgens would within a month or so prove fatal to about half the persons affected. A whole-body exposure of 700 or more roentgens in 36 hours would probably be fatal in all cases. A third-degree burn on a limited area of the body might not be very serious, but a second-degree burn over a large area might prove fatal. Similarly, a dose of 1,000 or more roentgens of radiation on a small area would cause local damage but probably few overall consequences. If most of the body were exposed to the same dose in 24 hours or less, death would undoubtedly result.

A neutron is a neutral particle—that is, it has no electric charge—and is present in all atomic nuclei, except those of ordinary (or light) hydrogen. Neutrons are needed to initiate the fission process, and they are present in large numbers after the fission and fusion reactions in nuclear explosions. Neutrons, being electrically neutral, do not produce ionization directly in their passage through matter. They can, however, cause ionization to occur indirectly as a result of interaction with certain light nuclei. When a fast neutron collides with the nucleus of a hydrogen atom, for example, the neutron may transfer a large part of its energy to that nucleus. As a result, the hydrogen nucleus is freed from its associated electron and moves off as a high-energy proton. Such a proton is

capable of producing a considerable number of ion pairs in its passage through a gas. By a similar mechanism, indirect ionization results, although to less extent, from collisions of fast neutrons with other light nuclei, for example, carbon, oxygen, and nitrogen. The ionization resulting from the interaction of fast neutrons with hydrogen and nitrogen in the tissue is the main cause of biological injury by neutrons.

The harmful effects of neutrons on the body are similar in character to gamma rays and can cause cataracts more readily than other nuclear radiations. At such distances from a nuclear explosion that they represent a hazard, nearly all the neutrons are received within a second of the explosion. As with other types of radiation, the neutron dose decreases with distance, partly because the neutrons spread over a large area (inverse-square law), and partly because of absorption and scattering.

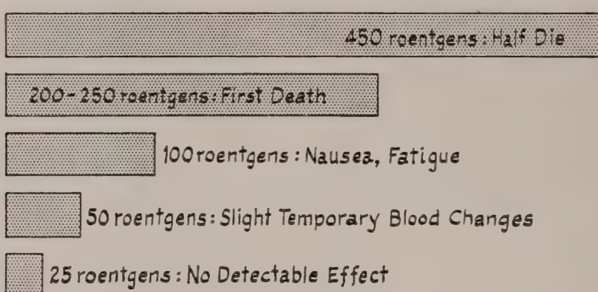

FIG. 7-9. Effects of gamma radiation dose with total body exposure within a 24-hour period.

Ionization is the dissociation of an atom into cations (with a positive charge) and anions (with a negative charge). This change is effected by the removal of one or more electrons from an atom, thereby disrupting the normal electric neutrality of the atom, which previously had an equal number of negatively charged electrons and positively charged protons. The removed electrons are negatively charged, and the remainder of the atom is positively charged. Each part is then an ion, and the atom is said to be ionized. Ionization can be achieved by chemical or electrical methods or by radiation. The phenomenon of ionization by radiation is utilized in monitoring devices, which indicate that their contents are being ionized when radioactive materials are within range.

It has been stated by some authorities that the radiation exposure of fire personnel should be determined by the fire chief. Theoretically, this is possible, but in those situations where immediate action is required, it is rarely possible to predict or evaluate accurately the radiation dose being received. This emphasizes the need for monitoring devices and for the training of fire personnel in their use. The National Committee on

Radiation Protection has stated that a single, once-in-a-lifetime 25-rem emergency dose should have no effect in the radiation status of the individual. Radiation status is an accumulation of 5 rem per year starting at age eighteen. Fire officers should be guided by this knowledge and should rely on monitoring devices as well as on help from specially trained persons.

Conclusions. Preplanning plays a predominant role in fighting fires that involve radioactive materials. With the information in this chapter, fire officers can preplan more effectively and obtain better results.

8

Effects of Weather

Wind. Wind velocity is an important factor in the initial stage of fire; 2 mph is considered optimum at this stage. Under favorable conditions, it is possible that fires of moderate proportions can be controlled by determined defensive measures if the wind velocity is no more than 15 mph, although wind also affects the use of hose streams (Chap. 3). As velocity rises from 15 to 30 mph, the rate of fire propagation from building to building increases enormously; at 30 mph even a relatively minor blaze, involving only two or three dwellings, may constitute a serious threat to all the downwind area. The exposure hazard to the lee of the fire is more severe, and it becomes increasingly difficult to set up a successful defensive line there. The spark and ember hazard is magnified, necessitating protecting lines well in advance of the fire.

Ground winds of more than 30 mph are conducive to the development of a *conflagration,* which is characterized by pillaring of heated air and products of combustion, rising several hundred feet in the air or more, depending upon wind velocity. The higher the velocity, the more the pillar slants from the vertical in the direction of the wind. In a conflagration, velocity on the lee side is materially reduced and frequently reversed in direction by the forces that produce the pillar of heated gases. This phenomenon may sometimes be noted at large brush fires and can possibly be utilized in making a firebreak.

Fire Storms. A fire storm may develop in the absence of ground winds sufficiently strong to promote a conflagration. Data from wartime ex-

periences indicate that an area less than 1 square mile is probably incapable of sustaining a fire storm. In addition, building density (the total ground area of buildings divided by the total area of the zone) must be greater than 20 per cent.

FIG. 8-1. A conflagration.

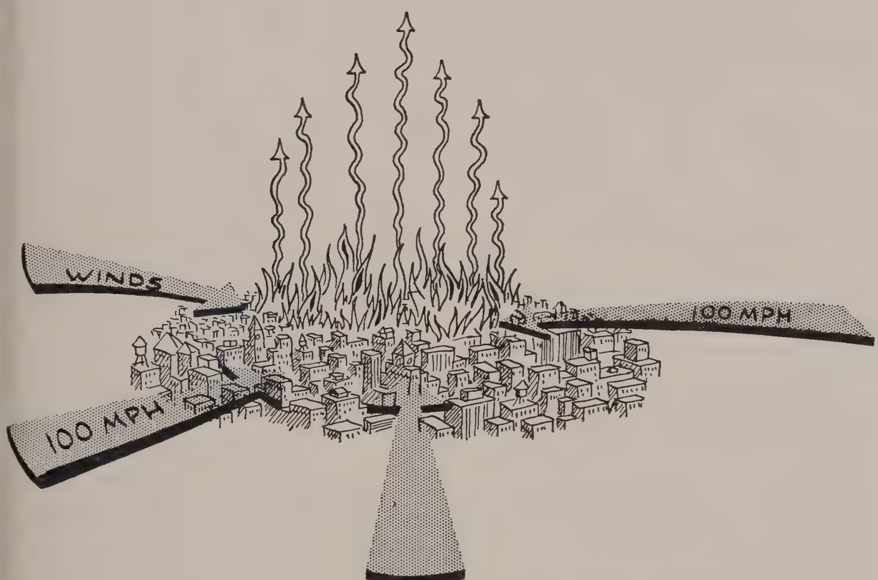

FIG. 8-2. A fire storm.

A fire storm is basically a wind storm; it may produce rain if the rising columns of hot smoke meet a stratum of cold air, causing the moisture in the air to condense around motes of soot and fall in large black raindrops. To the fire service, however, the fire storm is comparable to a conflagration in size but definitely different in other ways: it results from the merging of numerous smaller fires into one massive inferno and is much more likely to be a wartime than a peacetime phenomenon; minimum area and building density are essential; absence of a strong

ground wind is necessary; the thermal column (convection currents) rises almost vertically (that of a conflagration is bent over by the prevailing wind), and the rising column creates a powerful centripetal force that draws air along the ground at velocities that may exceed 100 mph, toward the expansive low-pressure area at its base; the true fire storm should not extend beyond its perimeter because of the centripetal pattern of the air currents created; high temperatures prevail, and combustible building material and plant life are consumed, with only brick and similarly resistant walls and charred trees remaining.

Underground shelters offer little or no protection, as judged by the Hamburg fire storm of July, 1943. Many persons, even though shielded from the searing heat, were found dead of oxygen deficiency. Conventional firefighting techniques are useless. The only possibility of successfully coping with potential mass wartime fires, in the author's opinion, is to develop military units capable of applying special extinguishing agents from planes or exploding shells, utilizing shock waves created and extinguishing agents disseminated thereby. Unfortunately, the armed forces are reluctant, if not actually unwilling, to participate in wartime fire operations, as indicated in civil defense hearings before Congress.

Special extinguishing agents could be such as the Russians experimented with in the Lake Balkash area in September, 1953, as reported by the British *Intelligence Digest*. During such tests, jet fighter-bombers flew over a test area at about 2,000 ft, seeming to eject a light spray. The result was an intense killing cold for a period of half an hour. All vegetation was killed, and trees became so brittle that they burst from the ground and froze hard. While the experiment allegedly was related to a military weapon, there are grounds for thinking that the Russians have developed a technique that might successfully cope with potential wartime mass fires.

Certainly, such an experiment warrants imitation. In the absence of an effective vapor, the discharge of the newly developed ABC dry chemical from planes or by means of shells at strategic spots in the fire area should be tried. Water cannot be expelled from planes in adequate quantities; with additives, it would be more effective but still scarcely adequate.

Low Temperature. Extremely low temperatures retard the initial development of fire, but they necessitate heavy clothing, thus encumbering firefighters, slowing their actions, and impairing the efficiency of the operation in general. Frozen hydrants are decidedly detrimental to stretching and operation of lines. Snow may impede movement and make it difficult to place apparatus favorably.

During cold weather, windows are generally closed, with several possible results: development of fire may be retarded, but the ventilation

problem may be increased; discovery of the fire and transmission of an alarm may be delayed, but the hazard to adjoining buildings may be reduced temporarily.

During operations, nozzles on hose lines must be kept cracked when not in use, in order to avoid freezing. Hose may be coated with ice, which causes it to stiffen. Care must be taken to avoid damaging the hose when it is placed on the apparatus.

The formation of ice on sidewalks, apparatus, equipment, and ladders can render some apparatus useless, increase danger for fire personnel because of insecure footing, increase the possibility of structural collapse because less water runs off, and necessitate the use of thawing devices during the extinguishing as well as the finishing-up, or "taking-up," phase. Apparatus may have to be started from time to time to prevent freezing. Officers must be vigilant to reduce the chance of injury and possible frostbite to their men.

Fire incidence increases with cold weather because the use of heating devices increases. Consequently, the possibility of having to fight simultaneous fires is greater.

High Temperature. Most conflagrations in the United States occur after an extended period of dry weather, generally accompanied by high temperatures. Prolonged hot weather is also conducive to an increase in the number and extent of brush fires. Hot weather affects fire incidence: more fires start in motors of domestic and commercial refrigeration units, air-conditioning equipment, and transportation units.

During the warm season, windows are usually open. This may abet fire spread but may also cause the fire to be discovered in its early stages. Firefighters become exhausted more quickly in hot weather; therefore, the need for more manpower should be anticipated and requested accordingly.

Humidity. Relative humidity is the ratio of the quantity of moisture actually present in the air to the greatest amount possible at the same temperature. Water vapor is part of the air: the higher the humidity, the lighter the air per unit volume. Humidity, therefore, has a controlling influence on wind and air-mass movement. The average prevailing humidity in any section determines the moisture content of wood and other combustible materials in roofed structures. The average air-dry seasoned lumber used in building construction in the United States has a moisture content of 12 per cent. The moisture content of wood in closed artificially heated buildings is less. Before wood can burn, this moisture must be driven out as steam, but this requires relatively little heat. The moisture content of wood, therefore, has a comparatively minor influence on the rate of fire propagation.

The humidity of the air, however, has a distinct bearing on the de-

velopment and propagation of fire. High humidity combined with inversion at the inception of a fire retards the establishment of a draft or pillar of heated convection currents (Chap. 1). Inversion refers to stratification of layers of air having different temperatures. The line between the two air strata is referred to as the floor of the upper stratum and the ceiling of the lower stratum. This line forms a barrier to convection currents until such time as temperatures develop to cause a break in the ceiling (a lapse).

Fires under high humidity and inversion are often characterized by dense smoke, poor visibility, and difficulty in ventilation. High humidity, and a consequent high moisture content in material exposed to fire, will make it more difficult for a vigorous fire to become established but will not retard propagation and spread once the fire is well started.

Rain and Snow. Rain greatly reduces the probability of fire spreading from building to building because it wets exposed sides and roofs of structures, thereby protecting somewhat against radiant heat. This effect is greater if the structures are unpainted since they absorb more water. Rain droplets cool convection currents but do not absorb radiant heat to any major extent. Snow does not retard the spread of fire to the same extent that rain does because surfaces are not wetted as much.

After snow or rain, melting or steaming on a roof during a fire might indicate the location of hot spots, where openings should be made.

PART 3

Firefighting Strategy

9

The Plan of Action

A major aim of this book is to help officers think at fires so that they can more readily and accurately contend with the two main questions frequently confronting them, whether they are lieutenants or chiefs: What are the problems? How are the problems solved? An officer's ability as a strategist can be measured by his reactions to these questions. Part 2 provides the answer to the first question, Part 3 the answer to the second.

Strategy, to be effective at any type of fire, should be characterized by quick and accurate analysis, maximum use of what is available, a knowledge of principles and skill in using them, an awareness of the need to anticipate and communicate efficiently, and good judgment, which includes ability to coordinate activities and common sense in making decisions. Strategy in the fire service is unique in that the enemy cannot be surprised but frequently can surprise. Unfortunately, strategy is not automatically improved by advancement in rank. It can, however, be improved with effort and experience. Putting the fire out is not satisfactory unless achieved with a minimum of hazard to personnel and a minimum of damage to contents and structure. In other words, an operation may be effective but not necessarily efficient.

A plan of action embodying sound strategy, applicable at any type of fire, should include the following steps:

1. Define the objective (major problem).
2. Decide upon the activities (derivative or work problems) essential to achieve the objective.
3. Assess the effects of pertinent factors on the required activities. Now

the commanding officer can calculate the types and approximate number of units needed.

4. Assign activities according to the objective of the operation and the functions of the units.

5. Provide adequate supervision so that the principles governing the functions of units are properly applied.

6. Take steps to ensure maximum use of personnel, apparatus, and equipment.

7. Use good judgment so that activities are coordinated efficiently and decisions are based on reliable information and common sense. Communications are most important here.

8. Be alert to anticipate developments and the need for countermeasures. Have alternative plan ready.

Steps 1, 2, and 3 of the action plan have been covered in Part 2. The remaining five steps are covered in Part 3. First, however, general consideration will be given to the art of firefighting.

Fig. 9-1. Efficiency at fire operations depends upon the knowledge (science) of the officer and the skill (art) with which he uses it.

The Art of Firefighting. Art involves skill and ingenuity as well as the systematic application of knowledge (science) obtained through field operations and study, in much the same way a physician learns by internship, practice, and study. As in other comparable fields, there is no substitute for experience in fire operations, and it has an important bearing on the art of firefighting. What can be learned from one experience and transferred to another are the fundamental principles involved. As one becomes adept in recognizing situations to which these principles can be applied, problems can be solved and techniques employed more effectively. Art and strategy obviously are closely related.

The art of firefighting should complement the science. As principles are discovered, verified, and applied to solve problems, they become the

working rules of the art—in effect, the rules governing the work problems of forcible entry, use of lines, ventilation, and so on. An officer must know not only the rules but also how to apply them with appropriate variations.

Reappraisal of Problem Areas. Up to this point, the more usual problems met at fires, such as forcible entry, use of lines, ventilation, and overhauling, have been stressed. In this reappraisal, the connection of other problem areas to the art of firefighting will be illustrated.

Assuming command may be a simple matter if the commanding officer arrives early in the operation. Otherwise, he must contact the officer being relieved, be briefed by him, and revise or modify the operation in progress. Field headquarters should be promptly established.

Determining the activities necessary to the operation may be simple if normal activities of engine and ladder units will suffice. It can be complicated, however, if there is uncertainty about the location and extent of the fire, the nature of the material burning and exposed to the fire, and the structural stability of the building. The necessary activities will vary with offensive or defensive operations and with a combination of both.

Determining what help is necessary may involve the transmission of additional alarms or calls for special equipment and apparatus. Additional manpower may be needed. Help may be required from public utility groups, ambulance units, and municipal agencies such as the police, health, sanitation, and welfare departments. Determining what help is needed can be complicated by uncertainty about the extent of the activity. For example, the commanding officer, who can readily see that ventilation must be effected, may not be able to determine so easily how extensive it must be.

Activities should be logically grouped: communications, water supply, welfare of civilians and fire personnel, and firefighting operations—all grouped separately yet still effectively harmonized. A communication system should be established to ensure prompt contact between field headquarters and subordinate officers in all parts of the fire area. In some departments, a communications unit can be called for this purpose. Water-supply activities should be grouped to attain desired pressures in mains, to select mains of adequate size, to choose vantage points for drafting water when practical, to select the most favorably located hydrants, and to lay out hose efficiently, particularly where heavy streams or chemical-foam streams are being used. Careful consideration of the welfare of civilians and fire personnel will ensure proper and prompt attention to their medical and physical needs. Firefighting activities can be grouped according to objectives and the functions of ladder companies, engine companies, and other units.

Assigning activities as specifically as possible prevents confusion and

increases efficiency. This can be done more readily after activities have been properly grouped. Fire-service units know what activities they generally carry out when assigned to "check exposures" or "open up the roof." At times, however, the officer should be emphatically specific, for example, whenever a unit might otherwise start operating above an uncontrolled fire. When withdrawing units and changing from an interior to an exterior operation, specific assignments will ensure a more orderly withdrawal. Specific orders should indicate the proper order to be followed in covering exposure hazards.

Delegating authority commensurate with responsibility in each case can be more effectively done when assignments are as specific as possible. When authority is definitely specified, several benefits will be realized: there will be less interference with the unity of command; there will be better cooperation from line officers entrusted with definite responsibilities.

Proper coordination of activities can be accomplished by effective discharge of the managerial functions (Part 4): planning, organization, staffing, control, and direction. Proper *planning* results in efficient selection of objectives and better use of policies and procedures. The objectives will more certainly be realized if plans fit together in terms of content, action, and timing.

Careful attention to *organization,* even at a fire operation, improves grouping of activities, assignment of activities, delegation of authority, and supervision and, generally speaking, produces a situation in which the authority and functions of the several units are clearly defined. Adequate *staffing* is necessary to coordinate the handling of grouped activities. Adequate *control* ensures more effective execution of plans. *Direction* pertains to guiding and overseeing subordinates; it has to do with getting things done.

Probably the most important element in achieving coordination, at fire operations or elsewhere, is the tradition of working together, which is more readily nurtured if all personnel understand the department's objectives and are familiar with what is done in units other than their own.

The *use of judgment* at fires is vital. Care must be taken to recognize and evaluate all the factors in the situation, and they must be assessed in the light of the total environment. This is essential to ascertain and accurately evaluate the existing problems. Sufficient time must be taken to reach a decision. At fires, decisions generally have to be made quickly; but in many cases it is both practical and possible to take thirty seconds rather than five to decide a point. Decisions should not be made without essential information. Common-sense decisions can be made more easily by an officer who has an adequate knowledge of firefighting as well as a

familiarity with problem-solving and decision-making processes. Decisions must be implemented at the proper time.

Use of Personnel. A skillful officer is one who uses what he has on hand (apparatus, equipment, and personnel) to maximum advantage and quickly anticipates additional needs. A commanding officer's skill is perhaps best measured by his ability to call forth the best efforts of his subordinate officers.

Personnel can be used much more effectively at fires if they have been trained to use apparatus and equipment skillfully, to carry out orders promptly, and to coordinate their activities with other units. Teamwork is more effective than mere numbers. Supervision is discussed below.

FIG. 9-2. Training plays a major role in developing firefighting skill.

Use of Apparatus. The full use of favorable features of modern, multipurpose apparatus enables a commanding officer to use his men more effectively. For example, when hydrant pressure is good, adequate supply lines to the pumper may permit favorable placement nearer to the fire. The powerful modern pumper is particularly suited to this arrangement, which shortens the lines from the pumper to the fire and requires less manpower. Many modern pumpers have booster equipment. One such apparatus approaching vehicular fires from each direction on a busy highway is almost invariably able to handle the job, thus making long stretches unnecessary. Aside from the type of pumper, men will be used more effectively (by reducing the number needed) if the officer uses the apparatus to stretch two lines, where it is advantageous, and exercises good judgment in selecting a hydrant or taking suction. These actions influence the number of lines that can be stretched from the pumper, the speed with which they can be stretched, and the manpower needed to stretch and use them. The snorkel has several important features that can be utilized along similar lines. Many phases of a fire operation, such as removal of occupants, use of lines, and ventilation, can

be carried out with less manpower and unquestionably greater ease and safety with this apparatus.

The modern metal aerial with its powerful propulsion potentialities, numerous safety factors, great structural strength, and ease of operation supplies the commanding officer with additional advantages. One man can operate the aerial, obviating in some cases the need for cumbersome portable ladders that may require four men. One man can also operate the aerial to ventilate front windows, using the propulsion power of the aerial. This power can also be used to raise a hose line to upper floors if the first length is properly folded and tied on the foremost fly ladder. With the hose arranged to pay out smoothly from the ground, the ladder and hose can then be raised to the desired height and position.

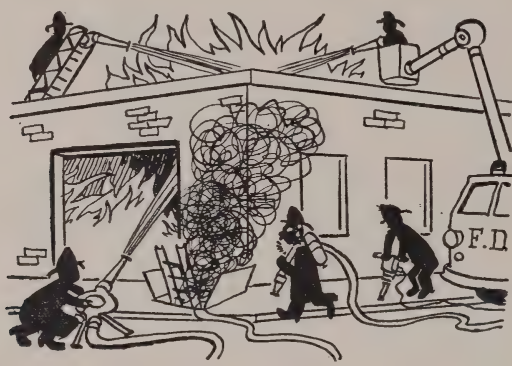

FIG. 9-3. The ability to use modern equipment to maximum advantage characterizes the skillful officer.

Use of Equipment. Many pieces of modern equipment enable a commanding officer to get more results from available personnel. Portable heavy-stream appliances equipped with wheel valves that permit control with a minimum of manpower mean more lines quickly operating. Some fire departments have devices with remote controls so that the stream can be directed from a comparatively safe spot, thereby reducing the chance of injury. Power tools are available, as is a lighter hose with many fine qualities. Foam necessary for class B fires can be supplied by fewer men if mechanical foam is used, and wetting agents can simplify the overhauling of baled material so that the job can be done more easily and with fewer men. Masks and protective clothing further reduce chances of injury and maximize the effective use of personnel.

Supervision of Personnel at Fires. Skillful supervision increases the efficiency of, and minimizes the life hazard to, firefighters. It is an outstanding component of the art of firefighting, but it is treated here as it affects more specifically the life hazard to personnel.

At all fire operations there is a life hazard for firemen. Operations should always be conducted with a view to minimizing the risk to firemen as far as is consistent with the goals of rescuing endangered persons and extinguishing the fire. Officers should exercise careful supervision to ensure that the lives of firefighters are not needlessly risked, for they have it in their power often to avert injury and even death. While reading the subsequent chapters on different types of firefighting units (Chaps. 10 to 12), the reader should keep in mind the need to minimize life hazard in deploying the responding units at fire operations.

As a first step in minimizing risk to firefighters, firemen should be properly clothed, wearing, as the situation requires, prescribed fire helmets, approved turnout coats, boots with inner soles, goggles, rubber gloves, work gloves, etc. In addition, they should be trained continuously to improve their skills, to avoid unsafe acts, and to recognize and be on guard against unsafe conditions. Supervision by superior officers is an important supplement to such training.

Rescue Work. Supervision can play a crucial part here because extreme risks to officers and men may be warranted when the lives of occupants are in the balance. Risks taken, however, should be carefully calculated. An officer should obtain as much information as possible about the number and condition of the people trapped, the location of the fire in relation to means of escape, and the available means of access to the occupants. He is then in a better position to anticipate the dangers and take necessary countermeasures, such as calling for more or special help, backing up the initial line or getting additional lines ready, providing means of escape via portable or aerial ladders, or providing exceptional ventilation.

It is of the utmost importance that the fire officer select the most feasible rescue method available. In making the selection, the hazards associated with the available means, such as aerial ladders, interior stairways, and fire escapes, must be considered. For example, if the aerial is to be used, the truck should be placed to utilize the most favorable angle of the ladder. Otherwise, rescue work may become dangerous because of the awkward angle, or it may be necessary to use the scaling ladder in conjunction with the aerial, a most hazardous procedure. Overcrowding of the aerial ladder, particularly the wooden type, should be guarded against. The exceptional height and restricted foot space on some of the newer aerials accentuate the physical hardships and difficulties imposed by the wearing of boots, fire clothing, and equipment. At lower levels rescues may be made more effectively and safely by metal aerials than by portable ladders. When occupants must be searched for in smoke-affected areas, firemen should work in pairs and officers should always know the location of the men. Contact between these pairs and

the commanding officer should be provided, preferably by using masks with sound-powered phones, so that necessary help can be quickly and accurately directed.

Stairways are ideal for rescue under favorable conditions, but they should not be used when they are exposed to heat and smoke from a fire below, particularly if the fire is not yet controlled and if the stairway is not yet vented.

Unsafe fire escapes, although difficult to recognize, particularly at night, should be avoided. No fire escape should be overcrowded. Where it is possible and feasible, occupants should be taken into the building from the lowest balcony and then down the interior stairway rather than down the straight-drop ladder.

Elevators are an attractive means of rescue, but at the same time they can cause delay and danger because of operating difficulties. Self-service types are especially hazardous. If there is doubt about the serviceability of an elevator, another means should be selected.

Roof ropes and life belts should, of course, be checked carefully and frequently. Masks are discussed below.

Forcible Entry. Supervision is important here because generally entry is not forced until hose lines are ready to protect the men making the entry and then to attack the fire. Premature entry endangers the men and may allow the fire to reach unnecessarily large proportions, thereby making extinguishment more difficult and dangerous. Well-timed forcible entry is an important part of a coordinated fire operation; disregard of this matter may result in numerous injuries, particularly in cases requiring roof ventilation (or side or rear ventilation, if practical and feasible) before opening up at or even below the fire level in order to avoid a back draft.

Some thought should be given to selecting the place to force entry. Will the spot selected facilitate the advance of hose lines, and thereby reduce hardships to firefighters, without, of course, driving the fire into uninvolved parts of the structure? Does it increase or decrease the difficulty of safeguarding a means of escape? At a fire in the rear of large occupancies, for example, it may be advantageous in some cases to force entry at the rear, nearer the fire, than at the front, from which lines must be advanced a longer distance.

At close quarters, men should be alert to the danger of swinging an axe, and light should be provided so that a man holding a claw tool has adequate protection. Care should be taken in assigning men to force entry from the exterior of a structure below ground level when space is restricted. A ladder should be in place or readily available, and if advisable, a line should be ready.

Ventilation. Supervision is an urgent matter here because, by its very

nature, ventilating requires officers and men to operate in precarious locations (roofs, fire escapes, on floors above a fire, etc.) and sometimes without the protection of hose streams.

Ventilating a roof can be extremely dangerous, and many firefighters have been injured or killed doing it. When an officer thinks that the extent of the fire makes work on the roof unnecessarily dangerous, he should take his unit off and notify his superior accordingly. Only the imperative need to assist a rescue operation justifies putting men to work on a hazardous roof. In such a necessity, men should take a roof rope with them, an aerial ladder should be placed in position and reserved exclusively for their use, and they should be ordered off the roof at the earliest possible moment. If a snorkel is available, it should be used to minimize the hazards.

Stretching and Using Lines. Men operating hose lines may be subjected to dangerous heat, smoke exhaustion, and effects of water. If the heat is caused by the fire, another line may be required to back up the first one. If an engine-company officer finds the heat so excessive as to make his position untenable, he should back his men out, using the line as much as possible to protect their withdrawal; this is especially true at cellar fires. He should not wait for orders to back out from the commanding officer, who may have arrived later on the scene and may not immediately understand the situation. If an officer in charge of a line feels that a second line is necessary, he should back his men into a position that provides a means of escape until the second line arrives. Officers in charge of lines should be constantly on guard against passing the fire, particularly in cellars.

Firemen may become exhausted in unusually hot weather just from pulling hose and getting the line ready to operate. Obviously, they should be relieved sooner and more often. Exceedingly hot weather may justify the transmission of a greater alarm to ensure adequate manpower.

The effects of getting wet at fires should not be underestimated, particularly in freezing weather. Firemen should be given a chance to change to dry clothing as soon as possible after they are soaked.

Finally, to avoid injuries, men operating interior lines should be warned and moved out of danger before outside streams go into action, lines should never oppose one another, and officers should ascertain that it is safe to use water as the extinguishing agent before starting it. Many injuries sustained when firefighters get off apparatus and prepare to stretch lines (stepping on hose butts, tripping over lines, etc.) could be avoided if the men were more carefully trained to stretch hose, a matter too often underrated.

Overhauling. Many men are injured during the overhauling stage, and officers should be especially conscious of their obligations to be

alert and informed about conditions. The following checklist will serve to minimize hazards:

1. Check for stability of the whole structure or of the floors affected by the fire. If the floor is weak, keep men out and work from the fire escape or from an aerial ladder, even if this limits the work to operating streams from these points. Keep a safe distance from weakened walls.

2. Shut off gas and electricity and make certain that men do not enter a flooded cellar until this has been attended to.

3. Effect the necessary ventilation before beginning overhauling.

4. Drain water from floors and out of cellar in order to reduce dangerous strain on the structure and to improve working conditions. If holes are needed for drainage purposes, make them where they will damage the structure least.

5. Cover and guard, if necessary, holes in floors and openings to shafts.

6. Utilize adequate lighting equipment.

7. Fold and remove any dangerous hanging pieces of metal ceiling.

8. During overhauling, use tools or equipment that are less likely to weaken the structure; for example, it may be better to use a saw instead of an axe when cutting a beam.

9. In overhauling contents, select the most feasible spot for the job, for example, to simplify work and avoid danger from heavy machinery on floors above.

10. Remove smoke-producing materials from the structure if practical and if working conditions are improved. The availability of wetting agents may make such removal unnecessary.

11. When material is removed from the structure via windows, a fireman should be stationed to warn off passers-by. If baled material is being removed, necessitating removal of the lintel on several floors, the row of windows used should be alternated to minimize structural weakening.

12. Be alert to the dangers of disturbing jars, carboys, and jugs. The contents may be inadvertently released, causing burns and explosions.

13. Where there is a dangerous dust hazard, avoid throwing dust into suspension, which will cause an explosion.

14. Ascertain what special hazards may require special precautions.

Officers should be more than usually thorough in training subordinates to eliminate unsafe conditions (potential falling objects, hanging metal ceilings, etc.) and to avoid unsafe acts (failing to wear goggles, inner soles, or work gloves) while overhauling.

The Use of Masks. Despite the increase in the number and types of masks for fire personnel, the number of injuries caused by smoke and exhaustion is still considerable. Masks in themselves do not prevent burns and exhaustion. However, injuries can be reduced if firefighters are trained in the use, maintenance, and limitations of the masks. Because

of the unusual gases that may be met in modern occupancies, supervising officers are advised to carry standard pamphlets issued by nationally recognized authorities describing such gases and their associated hazards.

It is important that masks be maintained so that they are available for immediate and safe use. Men have confidence when they are sure of their equipment. They should be taught how the mask functions so that they can make an effective inspection. The masks should be inspected frequently, and records kept of the inspections, in order to minimize the chance of defective masks being used at fires. When not in use, masks may have to be enclosed as a protection against weather, water at fires, etc.

Men should also be taught in practical drills how it feels to pull hose or swing an axe while wearing masks. They may have to be instructed how to take a mask off in smoke when visibility is zero and how to put it on in the dark (not in smoke). At fires some men are inclined to wait too long before putting masks on, and then they may put them on in a smoke-affected area. This emphasizes the need for continued training and supervision.

If firemen are injured while wearing masks, it may help to have the mask carefully checked. In some cases, the mask is immediately impounded and thoroughly examined for possible failure. Some departments have apparatus that can charge cylinders expended at fires and also replace used canisters. Thus, masks may be kept in service for long periods of time. Resuscitators and pnealators are also helpful to fire personnel overcome by exhaustion and smoke inhalation.

The author feels that the officer in command should specify how masks are to be used just as he specifies how other equipment, apparatus, and manpower are to be used. In congested areas of larger cities, preplanning necessarily plays a limited part; but it could be ordered that all units reporting except the engine company starting the first line report in with masks. If masks are needed, incoming masked units can take the line and advance it. The members of the first unit can then get their masks and be used as conditions warrant (to take over their original line or assist with another one).

Preplanning to a greater extent may be very acceptable in some areas. In others, simultaneous fires, traffic congestion, blocked hydrants, and even weather conditions may upset the best of preconceived plans. As a result, the unit assigned to reach the alarm box second or third may be the first one available to start a line.

Conclusions. Dangerous and ineffectual interior operations over an uncontrolled fire at which there is no life hazard for occupants should be avoided. An operation is considered dangerous when units are sent above the fire without being able to safeguard a means of retreat. An

uncontrolled fire is, for this discussion, one the commanding officer cannot honestly say is under control. The tactics referred to are also ineffectual, for the most part due to the heat and poor visibility. Better and safer results will be realized if sending men above the fire is delayed until the attack at the lower level is supplemented and control there appears imminent.

Fire personnel working above an uncontrolled fire have, in a sense, passed the fire in a vertical direction, placing it between themselves and a required means of escape. Many deaths and injuries result when the fire is passed, either horizontally or vertically. Backing a unit out of such a tough spot is no reflection on either officer or unit.

From the author's viewpoint, the most important item in the fire service is its personnel—and not the water supply, apparatus, or equip-

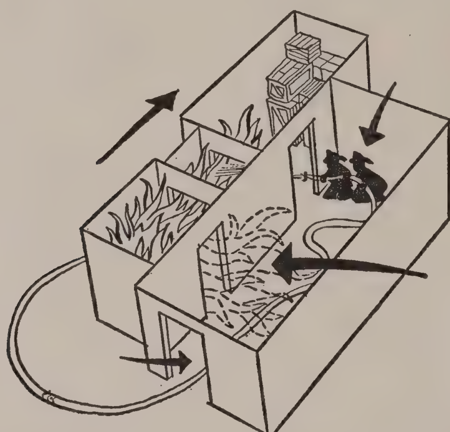

FIG. 9-4. Passing the fire vertically or horizontally can be extremely dangerous, since it may put the fire between the firemen and a required means of escape.

ment. Hence, the supervision of personnel at fires is the greatest responsibility of officers, who should be guided accordingly and be ever alert to the fact that their decisions and supervision directly affect the life hazard to their subordinates. Decisions will be sounder when officers learn how to recognize and assess the effects of various factors on the work to be done; supervision will improve when officers know what principles apply and how. The pertinent factors will indicate when water should not be used as an extinguishing agent, when interior operations are out of the question, when structural collapse is a possibility, and so on; the principles, with proper supervision, promote efficiency and safety.

Covering the Life Hazard. Rescue is always the first objective and is commensurately important to firefighting. The following checklist suggests the important points in covering a life hazard to occupants at structural fires.

1. Ascertain the location and extent of the fire to determine how and where occupants may be cut off by heat or smoke. Find out the number of persons endangered and their physical and mental state.

2. Assign units in accord with known information. Hose lines should be stretched and used as dictated by the life hazard (Chap. 10). Ventilation should be carried out so that it aids rescue work (Chap. 11). To gain access to the occupants, the alternate means available (stairs, fire escapes, snorkels, aerial or portable ladders, horizontal exits or bridging of ladders, elevators, and roof ropes) are considered and the necessary decision is made. An officer should make certain that men going in to search are properly masked and clothed and properly relieved, contacted,

FIG. 9-5. Means of removing occupants. The numbers indicate the suggested order of priority in removal.

and supervised. Helpful ventilation and protecting hose lines should be provided as the situation permits.

3. In effecting removal, the officer takes into account the number to be removed, their physical and mental condition, the order in which the occupants should be removed, and the means of removal available. Where elevators are available, they should be used to the best advantage possible and feasible under the circumstances. Taking victims down straight-drop fire escape ladders is a very difficult job, even when the victim is not heavy. In many instances, it is better to take the victim into the second-floor apartment, particularly if first aid is necessary or if he is poorly clad for the prevailing weather. Provisions should be made promptly for the welfare of victims.

4. Summon necessary help. This may take the form of a greater alarm or special calls for specific units. Rescue companies are especially useful because they carry resuscitators. Summon other help as needed from

hospitals, public utilities, and various community departments (police, welfare, sanitation, health, etc.). Some cities have disaster emergency setups.

5. Check exposures for the possible presence of a life hazard there. In some cases, life hazard in an exposure is the number one problem to be dealt with. If so, the first line (or lines, if necessary) is operated between the fire and the exposure so that rescue operations in the exposure can be carried out more effectively.

6. If panic develops in congested occupancies (schools, institutions, theaters, subways, ships, etc.), an effort should be made to allay it by use of a public-address system or other device. Lines should be operated so as not to interfere with the egress of the occupants.

7. Much can be done to reduce loss of life before the fire actually starts; here lies the greatest responsibility of the fire service. Fire prevention is of tremendous importance. The skillful use of well-selected apparatus and equipment and of well-trained personnel play an important role, of course. In addition, a truly maximum effort should be made by the fire service on a national basis to analyze the facts associated with, for example, those fires at which approximately four thousand young children die annually in the United States. It may be that there are outstanding features about these fires (for example, many casualties slept on upper levels of one-family houses) that the public could be informed about, thereby reducing the number of casualties. Any action that might reduce the number of deaths by the slightest fraction is worthy of consideration.

Covering Exterior Exposure Hazards. Skill in this and other important areas can be developed by learning how to apply the suggested plan of action along the following lines:

The assumed objective is to confine, control, and extinguish the fire, with emphasis at this point on "confine." The activities essential to this objective may include forcible entry, ventilation, examination, use of lines, closing windows or inlets to air-conditioning systems, communications, moving contents from exposed positions, and putting out incipient fires.

Some of the most pertinent factors in such situations are the location of the fire, its extent, construction, auxiliary equipment, water supply, occupancy, equipment and apparatus available, proximity to fire, and direction and velocity of the wind. By assessing the effects of these factors on the use of lines, for example, the commanding officer will know the priority to be followed in placing and using lines and the types and approximate number needed. A more complete picture is obtained by noting effects on all essential activities.

After units have been assigned to carry out their various functions,

supervision is very instrumental in ensuring maximum use of personnel, apparatus, and equipment. For example, the use of lines should be supervised so that sprinkler or other similar protective systems are promptly and properly supplied and master or other streams are employed in accordance with governing principles (Chap. 10). If lines are to be used in exposures, the mobility of the $1\frac{1}{2}$-in. hose should be remembered.

On arrival at some situations, it may be compulsory because of the location and extent of the fire and the severity of the exposure hazard to use all available lines for defensive purposes. Heavy-caliber streams should be used to wet down exposures or set up water curtains, if they will suffice; it must be kept in mind that most radiant heat passes through drops of water and through ordinary window glass. In extreme cases, lines may have to be applied constantly to the exposures in order to avoid involvement. When conditions warrant, defensive lines can also be used offensively.

The importance of anticipating future developments cannot be overestimated. The necessary manpower, equipment, and apparatus should be on hand before a possibility becomes real. If an interior operation has to be abandoned, the fire building will become more fully involved, thereby intensifying the exterior exposure hazard. Additional alarms should be transmitted so that the necessary defensive alignment can be set up. If there is a possibility of structural collapse, more extensive measures must be taken to contend with an expected worsening of the exposure hazard.

Communications play an important role in this part of the fire operation. Through portable devices, the commanding officer can keep abreast of developments and take effective and timely countermeasures. In addition, incoming units can be directed by radio how to approach the fire area and where and to whom to report, and thus be put to work more quickly and efficiently.

To assign and supervise activities as suggested in the action plan, an officer must know the functions of the various units and the principles governing these functions. Engine, ladder, and rescue and squad companies are discussed in Chaps. 10, 11, and 12.

10

Engine Companies

It is the responsibility of the engine company to provide water to maximum advantage for rescue or extinguishment. Officers make a very serious error if they engage in rescue work without first providing required streams. Where a hose stream is essential for covering a life hazard, the engine company responsible should stretch and operate that line in preference to any other activity.

In addition, other considerations govern the placing and use of hose lines.

If There Is a Life Hazard. Initial action is greatly influenced by the presence of a life hazard. If necessary, operations to control and extinguish the fire must be temporarily neglected in order to cover the life hazard adequately. The first line should be stretched and operated between the fire and the endangered occupants or between the fire and their means of escape. If an occupant showing at a street-front window is obviously endangered by flame, a protective stream should immediately be operated from the street so that rescue can be effected via ladder or other means. A hand line or a deck pipe can be used for this purpose. Similar exterior action should be promptly taken where a mushrooming fire has driven the occupants of the top floor to the fire escape, where they are threatened by flames from windows below. It must be kept in mind that heat and smoke can be driven in such a manner as to endanger occupants trying to descend by the interior stairway or to endanger fire forces attempting to advance a hose line from the interior. The effect is particularly injurious when victims are caught in passage-

ways and hallways and are then subjected to the full brunt of the driven heat and smoke. A smoke condition in itself is not sufficient reason for using an exterior line as described, but a line should be held ready to operate from the street or some appropriate spot if more severe conditions develop before rescue is completed. Visible life hazard must be cared for as soon as possible; of course, prompt steps must be taken to cover the probable life hazard (Chaps. 9 and 11).

Fig. 10-1. Covering life hazard from the street.

Fig. 10-2. Covering life hazard with an interior line.

Where vertical shafts are carrying the fire upward in an occupied building (five-story, 40 by 70 ft in area, nonfireproof), the objective of the first line is to protect endangered occupants. The best way to achieve the objective is to use an all-purpose nozzle at the most practical low level and inject fog, which will vaporize, rise, and exert a powerful extinguishing effect in the shaft and adjoining channels. The solid stream can be used on and off to put out the fire at the base of the shaft, assuming that the fire there is minor and that the level of operation is above (for example, at the street level). The second line, frequently needed, can be stretched dry to the appropriate upper level, usually the top floor, and then supplied with water if necessary and used as required. The officer who advances his line to the third or fourth floor before using water on the shaft fire violates the cardinal rule governing the use of hose lines when there is a life hazard, since he did not operate his line between the occupants and the fire on the lower floors, assuming that the fire originated at the base of a dumb-waiter shaft.

If the firemen working the first line are in a dangerous position, the second line should be stretched and operated to protect the line of retreat for the first line, to put out any fire passed by the first line, and to help ensure attainment of the first line's objective. The men selected to carry out an important and hazardous assignment should be given every protection available, and the use of masks, fog, coordinated ventilation, etc., should certainly be considered.

Every type of fire involving life hazard obviously cannot be covered here, but the fundamental principles mentioned are applicable at any fire. While covering the life hazard, control and extinguishment of the fire may be simultaneously effected; that is a desirable achievement, of course, but the primary objective is rescue.

If There Is No Life Hazard. *One-line Fires.* One-line fires generally can be located readily; they are usually accessible to attack and limited in extent; usually, but not always, they involve contents only. At such fires, lines should be placed and operated to prevent extension while efforts are made to extinguish. Therefore, the line is generally placed so that it can be advanced from the interior, driving the heat and smoke out of the building. This way, involvement of, and extension through, vertical and horizontal channels can best be prevented. Exceptions to this rule may occur at buildings under construction or under demolition, where, due to various hazards and delays associated with an interior operation, an exterior line may be feasible (Chap. 6).

Use of Second Line. If the first line cannot successfully advance and extinguish, it may be practical to back it up with the second line or withdraw it to the hallway or stair landing, close the door of the involved occupancy, and concentrate on preventing extension of the fire while an

effort is made with the deck pipe from the street, with a multiversal nozzle from side or rear, or with a hand line from the fire escape to reduce the severity of the existing fire conditions. Firemen inside should be warned before exterior lines are used. Protection of fire personnel is paramount here, but every possible effort should be made to achieve the purpose of the withdrawn line, which is to prevent fire extending from the involved occupancy into horizontal or vertical channels. Lines should be placed accordingly. When it seems wise, exterior lines can be shut down and an effort to advance from the interior repeated, reinforced by an additional line if necessary.

If structural members such as partitions and ceilings are involved, it is generally advisable to have a second line stretched and available to check extension while the first line is extinguishing the main body of fire or to assist the first line in controlling the fire on the originally involved floor so that a third line may be sent to the next higher floor and still have its line of retreat safeguarded. To order a second line stretched and then not use it does not necessarily reflect badly on an officer, as experienced firefighters know. When specific and complete information is not readily available, in the early stages of an operation, it is necessary to surmise, anticipate developments, and take appropriate countermeasures, such as stretching a second line, which subsequently may prove unnecessary.

Use of Multiple Lines. Multiple lines (three or more) may be required where a second line has been tried unsuccessfully. Every effort should be made to sustain and implement an interior operation. This may require a battery of lines if advance on a wide front is in order, as at fires involving large-area occupancies, such as churches, piers, armories, and department stores. Such lines should be placed and operated to drive heat and smoke ahead and out of openings made by ladder companies to minimize exposure hazards while helping to extinguish.

At fires that are definitely beyond the ability of the assignment on hand to extinguish and when nearby structures are endangered, the first line should be used to protect the most severe exposure. Ordinarily, the second line should cover the next most severe exposure, and so on, unless some exposures require coverage by more than one line. Available manpower and equipment are utilized to provide maximum protection for the structures exposed, usually in the order and manner dictated by the severity of the exposure. The severity depends upon the effects of the pertinent factors present (Chap. 9). Needed assistance should be anticipated and summoned.

Existing circumstances warrant variation in the use of lines. For example, the first two lines may be used to cover one exposure if firemen on the first line need the protection of the second to make their position tenable in the heat. In some cases, lines can be used both to protect the

exposures and to attack the fire. Departments supplied with remote-control portable pipe appliances should take full advantage of this equipment in setting up defensive alignments.

Fires may travel through concealed spaces inaccessible to attack by interior lines. This may involve the structure to such a degree that interior positions are untenable or inadvisable. The interior operation must then be temporarily abandoned in favor of an exterior operation. This also holds true if structural weakness of the fire building is anticipated. In changing from an interior to an exterior operation, the men in the most hazardous position should be withdrawn first and then the men in the next most hazardous position. Units operating lines covering the escape of men on other lines should withdraw only after their assignment has been completed. Orders to abandon lines should be obeyed promptly.

Officers withdrawing from interior positions may be able to supply helpful information for setting up and carrying on the exterior operation. Information on the location of the fire, the manner in which stock is stored, etc., could result in better direction of exterior streams and effective breaching of walls.

The first lines out of the fire building should, if necessary, be used to cover the men withdrawing remaining lines. Otherwise, they can be placed in new and effective positions to cover newly created exposures. The change from an interior to an exterior operation generally necessitates the transmission of a greater alarm. This need, of course, should have been properly anticipated and acted upon. Lines from the greater-alarm units can be used first to set up a protective alignment for units retreating from the fire building and later to supplement the coverage for exposures, actual or anticipated. When the fire shows signs of abating, an interior attack can again be contemplated.

These principles apply at any fire; the efficiency with which they are used depends upon the extent to which they are understood and the skill with which they are applied to prevailing conditions.

The mechanics of stretching lines varies in different departments and different sections of the country, and fire personnel are governed in this respect by their own regulations. However, all officers should have a working knowledge of universally accepted principles of hydraulics to ensure adequate pressures at the nozzles of stretched lines.

Engine companies at times engage in other phases of a fire operation, such as ventilation, overhauling, and salvage. In such cases, they operate fundamentally along the lines prescribed for ladder companies (Chap. 11).

The Role of Surmise. In some cases, it is extremely difficult to know just how the fire is extending in its early stages. Heat, smoke, poor visibility, and pressure of time all militate against an officer having all

desirable information at his fingertips when fire operations begin. *Surmise,* therefore, must be depended upon to some extent where conclusive knowledge is not readily available.

An effective surmise can only be formulated after a serious effort has been made to locate and determine the extent of the fire.

Surmises are, in effect, educated guesses, made with a definite consciousness of the responsibility involved and the limitations imposed. They reflect the ability of the fire officer to recognize and evaluate pertinent factors as they affect the placement and use of hose lines. Experience and judgment naturally play a major part in an effective surmise. As operations become complex or if rescue work must be undertaken, it becomes increasingly imperative to formulate surmises based on the most complete and reliable information available.

11

Ladder Companies

The major assignments of ladder companies are to rescue occupants, force entry, ventilate, check the fire building and exposed buildings for possible fire extension, and to overhaul, which includes salvage work.

Rescue Work. Generally speaking, an officer initiating rescue work is guided by the checklist in Chap. 9 (see Covering the Life Hazard). In addition, hand lights help in making a search. In some cases, particularly when the rescue work is being carried out on the street side, apparatus searchlights can be used to advantage. Luminous clothing provides an additional safeguard for firemen, who should work in pairs during rescue operations. This clothing also facilitates supervision. Walkie-talkies or masks with sound-powered phones should be utilized to maintain contact during rescue work and to call for assistance if necessary. Firemen should, of course, be properly trained as to where and how to search.

Ladders, both portable and aerial, play an important part in rescue operations. Good judgment is important in selecting the appropriate ladders with due regard to available manpower, reach, angularity, accessibility, overhead obstructions, street grade, fire location, and wind direction. An officer should be familiar with the advantages and limitations of all ladders. The *available manpower* must be used effectively. Ladder companies often have less than five men and an officer, and at least two men will very often be assigned to effect ventilation to help the rescue work; consequently, there may be no more than four men available to raise ladders. The officer should, if possible, utilize the bed ladder of metal aerials, which can do the job with one or two men. In addition,

the metal bed ladder provides greater security and can be put into position more quickly than portable ladders.

An officer should be aware of *reach* limitations, and select a ladder that is suitable for use on the floors and roofs involved. *Angularity* varies with the distance between the base of the ladder and the building and with the height of the objective (for portable ladders, some departments determine the distance to be the length of the ladder divided by 5, adding 2 to the quotient; thus, the base of a 35-ft ladder is placed 9 ft from the building). Satisfactory angularity with aerial ladders depends in large measure upon the type of ladder. Owing to greater strength and to guard rails, metal aerials have a greater acceptable angularity range than wooden aerials. *Accessibility* refers to those features of a situation which permit or prohibit the use of ladders. For example, many large modern housing projects have features that prohibit approach by aerial trucks and use of aerial ladders. Railings, hedges, raised terraces, inadequate openings, sidewalks blocked by trees, and lack of roads strong enough to sustain fire apparatus may make a structure inaccessible to ladders. *Overhead obstructions* are trees, lampposts, overhead wires, elevated railroad structures, etc.

Only ladders that serve a useful purpose should be raised. Excess ladders waste time and manpower, perhaps at a critical time, and obstruct stretching of lines and operations in general. When portable ladders are required in rescue work, the proper size should be promptly selected. A ladder that is too long or too short may make the rescue unnecessarily difficult, if not impossible, and delay in selecting a more suitably sized ladder may be fatal. Selecting proper portables for windows of various heights can be practiced at outdoor drills. Some departments have procedures for using portable ladders to bridge spaces between buildings for rescue purposes. These observations do not apply to portable extension ladders.

A scaling ladder is a portable ladder with a metal hook at the top, which is designed to span window sills and enable the user to climb up. To go down, the user descends from the hooked sill, removes the hook from the sill, lowers the ladder and hooks on the lower sill, and repeats the process as many times as required. Although scaling ladders are seldom used at fires, some outstanding rescues have been made with them where the aerial ladder was short of the target. The rescued persons should almost always be brought in on the floor below the fire unless it is compulsory to continue down the aerial ladder.

The aerial ladder is often used in rescue work. It is extremely important to place the aerial truck as favorably as possible to expedite rescue operations. On streets with exceptionally wide sidewalks, it is advisable to place the truck on the sidewalk if there is any doubt about

the aerial being able to reach its target or about the resulting angle. Ladders should be placed in some cases against the building at either end of fire-escape balconies to facilitate removal of rescued occupants. The windward side is preferable unless the location of the fire or the grade of the street and the height of the objective dictate otherwise. In any event, a protecting line should be available to operate between the fire and the endangered occupants. This procedure may be necessary if overcrowding or panic threaten or if occupants using fire escapes cannot get past a fire on a lower floor. There is a tendency to overcrowd aerials in rescue work, and the officers should guard against this.

Because of obstructing apparatus or other conditions, the aerial ladder must at times be used at an oblique angle, and members of ladder companies should be instructed and trained accordingly. The use of an aerial at an oblique angle has advantages. It is preferred to get the

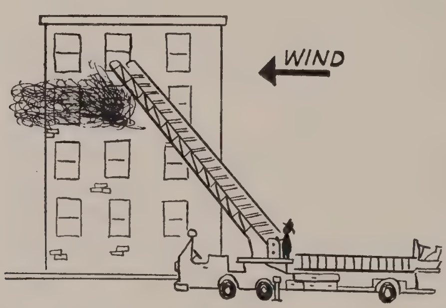

Fig. 11-1. The aerial at an oblique angle from the windward side lessens exposure to heat when the fire is below the point of rescue.

benefit of a prevailing wind that is blowing the heat and smoke in a direction that facilitates rescue. Where there are two targets (trapped occupants) some distance apart and only one aerial is available, rescue can be achieved more quickly and from one position by using the aerial at an oblique angle. It may be advisable to position the truck midway between the targets however, to minimize the obliqueness of the angle at which the ladders are to be used. At fires where streets are steeply graded, the aerial may be used more effectively at an oblique angle from the high side of the fire building to ensure better reach.

The disadvantages of placing an aerial at an oblique angle are that it must be raised higher than if the platform is directly in front of the target, unless the truck can be positioned nearer the building. This is not always possible or feasible. If windows are only about 2 ft wide, which is the case in many residential buildings, the use of the aerial at an oblique angle to remove an occupant will necessitate taking out the upper and lower parts of the window to provide sufficient room. Metal

aerials with high guard rails make rescue extremely difficult in such cases. Ladders placed at an oblique angle in a window may create undue strain at the base of the aerial if a twisting force is exerted. Metal aerials raised at an oblique angle to metal roof cornices or rails of fire escapes tend to slide, increasing the strain at the base of the aerial. This tendency to slide is aggravated by the weight of fire personnel and equipment.

A decision must sometimes be made between raising the aerial to the roof for venting or using the aerial first to remove an occupant. Roof

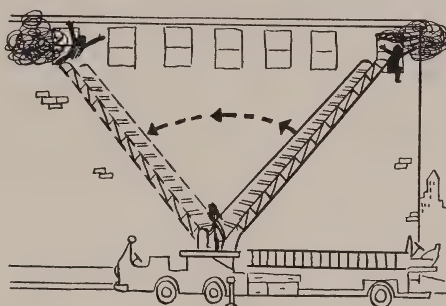

FIG. 11-2. With only one aerial available in this situation, position the truck so that rescue can be performed with the ladder at a minimum oblique angle.

FIG. 11-3. Placing the aerial at an oblique angle from the upgrade side of the fire may better ensure that the target is reached.

ventilation will very often help a rescue operation, but the endangered person may not be able to survive while the aerial is first used to vent the roof. If an officer has any doubt in such a situation, the aerial should be used for rescue first. In the meanwhile, a man may be sent to the roof via a rear fire escape if one is present. If adjoining structures provide ready access to the roof of the fire building or if more than one aerial is available, both objectives can be attained.

It may be argued that the roof should be vented first in the interest of other tenants. However, the presence of other endangered occupants may

be only problematical, whereas the visible endangered person is a fact. Experienced fire officers can readily recall numerous occasions on which occupants of fire buildings have successfully vacated the premises under amazing circumstances and without the aid of the fire department, and it is quite possible that the visible occupant is the only one remaining. The probable life hazard must always be considered, however, and operations are conducted accordingly.

Forcible Entry. There is an understandable relationship between forcible entry and ventilation. For example, it may be necessary to wait for roof ventilation before forcing entry at lower levels in order to minimize the possibility of a back draft. On the other hand, forcible entry at doors and windows may be necessary to achieve more complete ventilation. Since the fire department has the responsibility of protecting life and property against fire, it is given commensurate authority to force entry into a structure if necessary to discharge its responsibility. This authority is unique: no other agency has similar power to force entry into public, commercial, and residential structures. However, there are some limits on fire-department jurisdiction where fire involves or endangers foreign vessels and embassies or federal-bonded warehouses and restricted military areas.

Forcible entry is usually considered to be the work of ladder companies, but all branches of the fire service should be trained and equipped for this job in the event that ladder companies are not on hand. If life hazard is involved, entry should be forced as soon as deemed advisable for rescue purposes. If a building is vacant but heavily charged with heat and smoke, entry at lower levels should be delayed until the roof has been vented to minimize the chances of a back draft. In some cases, the small extent of a fire may warrant waiting briefly for a key instead of breaking expensive doors. In some commercial districts, representatives of protective agencies practically roll in with the apparatus, and they may have keys for the involved occupancies. In hotels, keys supplied by the management may simplify entry into rooms when investigating an unexplained odor of smoke, since many rooms may have to be checked. In ordinary fires, forcible entry is not effected until a line is on hand and ready to operate. In some instances, a door may be forced but held closed until the line is ready. In extraordinary situations at which unusually extensive fires are anticipated, more than one line should be available when the structure is opened up, and forcible entry is timed accordingly.

Good judgment must be exercised in deciding where to force entry. Consideration must be given to peculiarities of construction, presence or absence of life hazard, location and extent of fire, occupancy involved, time of occurrence, direction and velocity of wind, and equipment avail-

able. Generally speaking, forcible entry is effected where it best facilitates ventilation, examination, search, and removal of occupants. In some cases, forcible entry is achieved via ladders into upper floors to avoid interfering with the escape of occupants through lower exits.

Officers should be familiar with the types of forcible entries they may meet so that proper procedures and equipment are promptly employed. Ladder companies in some areas should be provided with cutting torches to ensure that they can force entry in the most desirable manner and location. Equipment, of course, should be maintained in good working condition and men should know how to use it efficiently.

Ventilation. Ventilation at fires may be defined as the controlled circulation of smoke, heat, and gases. It is usually considered to be the work of ladder companies but may be carried out by other units. It is important that engine companies be trained to ventilate in situations where

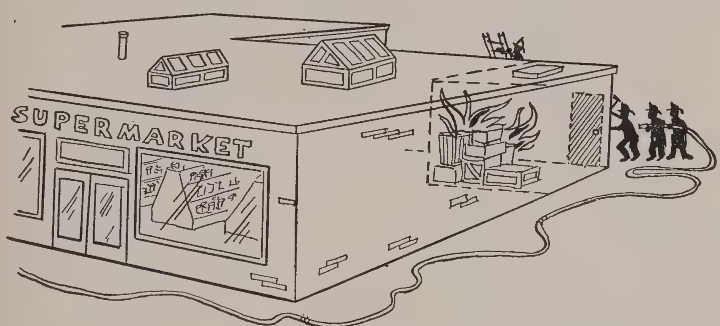

Fig. 11-4. The location of the fire influences the location of forcible entry—at the rear rather than the front in this case.

ladder companies are not yet on hand. Ventilation may be accomplished in two ways: by natural means, which may involve the use of doors, windows, bulkheads at roof level, deadlights, and openings in the floors or roofs; by mechanical means, which may involve portable fans, smoke ejectors, exhaust systems, and fog streams. Natural means of ventilation may be supplemented by axes, claw tools, hooks, ball and chain, power tools, aerial ladders, and heavy streams, including fireboat streams to vent roof bulkheads on piers. The use of masks, of course, can play an important part in effective ventilation.

If no life hazard is present, ventilation should be coordinated with the work of the engine company, as premature venting can cause rapid spread of fire. An officer assigned to vent at a fire escape should try to time the venting with the arrival of water at the nozzle of the engine company assigned to move in from the hallway. If he is on the street side, he may hear the pumper as it starts to deliver the water or he may

actually see the line stiffen out. In some cases, he may hear the ladder company as it starts to force entry from the interior.

Generally speaking, if roof ventilation is necessary, it should be effected as soon as possible. If it creates or intensifies an exposure hazard, firemen should wait for protective lines before venting. Effective roof ventilation does much to prevent back drafts at lower levels and to give the officer in command a better chance to determine accurately the location and extent of the fire. Where back drafts are possible, fire units at lower

FIG. 11-5. Means of venting a structure. Other means include fans, air-conditioning systems, and fog systems.

levels should not enter until roof ventilation (or side or rear ventilation, if feasible) has been effected. If life hazard is present, any ventilation essential to the rescue work should be carried out regardless of whether protective lines are present or fire conditions are worsened.

If the objective is to localize the fire, ventilation is usually achieved by opening up as directly over the fire as possible. Where a fire is extending into the cockloft via a vertical channel, opening the roof as directly as possible over the channel will minimize horizontal spread (mushrooming) in the cockloft. Opening the roof in the wrong place can mean the difference between a first-alarm and a fourth-alarm fire.

Sometimes ventilation can serve simultaneously the double purpose of helping to cover a life hazard and to extinguish the fire. However, where

such ventilation is not possible, covering the life hazard is the first consideration: then openings must be made to draw the heat, smoke, and gases away from the endangered occupants, even though the fire condition may be intensified.

The practice of opening up directly over the main area of involvement may not always be practical for cellar fires. Conditions may require

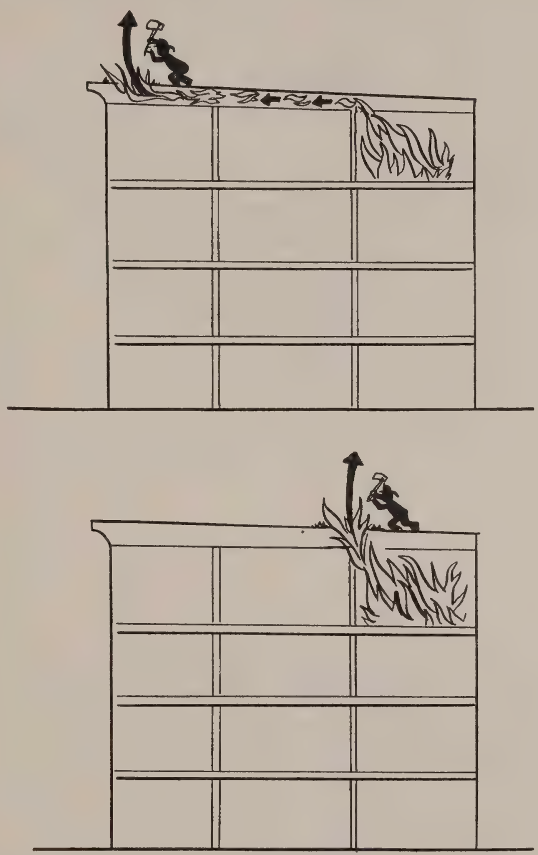

FIG. 11-6. Opening the roof in the wrong place (top) and in the right place (bottom).

opening up the ground floor near windows that will best help ventilation. In fires on intermediate floors, horizontal ventilation may suffice; if not, it may be supplemented by venting via appropriate vertical channels. Horizontal ventilation generally suffices in fireproof buildings, although it is often necessary to relieve smoke conditions on floors ten to fifteen stories above the fire because smoke ascends through elevator shafts.

Ventilation by means of elevator shafts is not recommended because it

may endanger occupants of an elevator car, because the open shaft door creates a hazard for fire personnel, and because unnecessary damage to cables, rails, and machinery may result. The need to assist rescue work, however, might override the last two objections.

When making openings on a roof, an officer should keep in mind the following checklist:

1. If the structure is heavily involved, do not jeopardize firemen un-

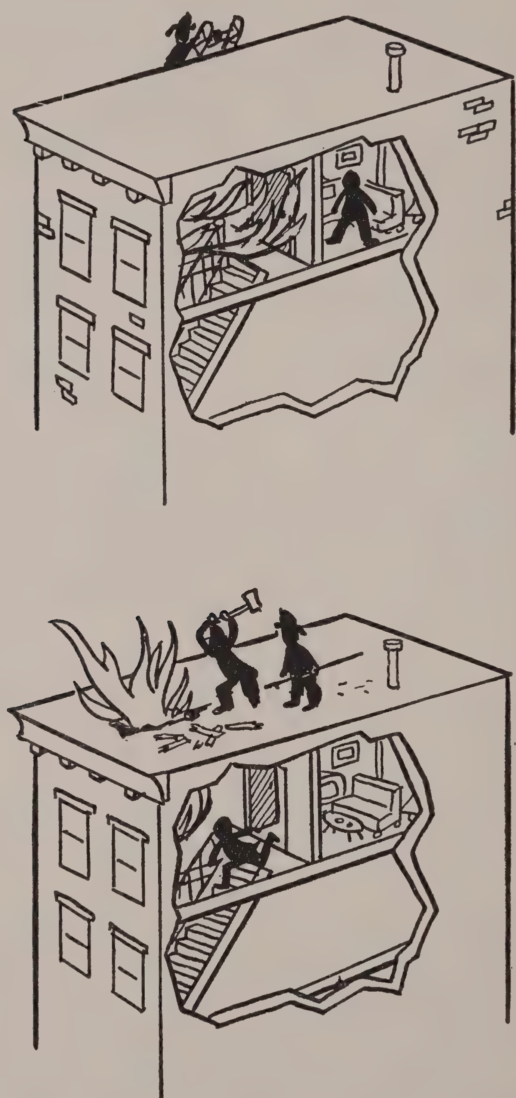

FIG. 11-7. Venting the roof so as to assist rescue work.

necessarily by remaining on the roof too long. In any event, have a roof rope available as a means of escape. If possible, have an aerial in position as a safeguard.

2. Keep in mind the objective of the roof work. If it is to aid rescue work, this affects when and where to ventilate and the risks to be taken.

3. Where there are equally effective alternatives for venting a roof, the alternative with minimum exposure hazard should be used.

4. The size of the opening should be adequate for the purpose, and work should be done with backs to the wind, thereby minimizing physical effects from the smoke issuing forth. Provide masks and lighting if they are needed. Have protecting lines when needed.

5. Make the openings over the hot spot, which may be indicated by melting tar or steam on a wet roof or may be found by feeling with the hands. Try to get some idea of the location of the main body of fire before going to the roof.

6. Exercise careful supervision to avoid unsafe acts and conditions.

7. The amount of structural damage done while ventilating should have a reasonable relationship to the extent of the fire.

Ventilating from fire escapes has many dangers, and great care must be exercised to avoid being cut off. The hazards are greater on rear fire escapes, since danger cannot be detected as quickly and also since protecting hose lines cannot be set up as quickly by deck pipes or even hand lines.

To relieve a smoke condition from fire escapes where there is no life hazard, the best procedure may be to work down from the top floor (it is assumed the roof has already been opened up), opening the remote window first, then the next remote window, etc. It is important to keep in mind the direction of the wind; otherwise, the venting operation may become very difficult after one window is opened. It may be best to enter the floor from the fire escape and open the nearest window and then the next nearest. This procedure is generally followed where conditions are difficult and ladder companies have to search for and remove occupants. A severe smoke condition with no life hazard to occupants initially warrants an exterior rather than an interior ventilating effort. However, in many cases, exterior work supplements an interior attempt.

In venting floors above the fire with aerial ladders from the street-front side, it is important to enter and search the vented floors as soon as possible, particularly in residential buildings. Prompt entry from the aerial may be possible, since in all probability roof ventilation is going on at the same time, further relieving conditions on the upper floors. In many instances, the ladder company that has vented the roof starts down the rear fire escape and, working from the top, vents, searches, and examines the upper floor in the rear.

To ventilate efficiently, officers should understand what ventilation is from the fire-service viewpoint as well as when, where, how, and why to ventilate. The principles set forth above apply to all types of fires at which ventilation is required. As with all principles, one must learn to apply them with variations warranted by the circumstances.

Checking the Fire Building for Extension. This phase of firefighting requires a knowledge of how fire spreads by conduction, convection, and radiation (Chap. 1) as well as a knowledge of various types of construction and the effects of concealed spaces (Chap. 6). An officer must determine quickly and accurately whether the greater danger of extension is vertical or horizontal.

In a real sense, ventilation is a necessary prelude to checking for extension. In addition, since ventilation is designed to control the direction of the fire, it is an important supplement to checking.

Hose lines should be ready when openings are made. Experience and judgment enable an officer to open up a ceiling at a reasonably practical distance from the main body of the fire and cut it off effectively. If the ceiling is involved at the opening, the line should be used to knock down the fire. Then opening should be repeated at a point more distant from the main body of the fire until it is certain that spread in this particular direction is checked. If the first opening shows a clear ceiling, another should be made nearer the fire. The most desirable opening is at the point the fire is just approaching. The line is then used to drive the fire back, and the checking operation becomes simpler.

While checking vertical channels, the advantages of fog should be kept in mind, as it does very effective work beyond the place of application. Fog from an applicator can likewise be used to check extension through ceilings, especially if ceilings are high and tough to pull on intermediate floors. Openings just large enough to insert and operate the applicator will suffice. However, too much fog at one time may blow the ceiling down by its rapid and forceful expansion in volume (more than 1,600 times) as it vaporizes into steam.

Except for rescue purposes, officers should never try to get ahead of the fire and drive it back to its place of origin when such a move entails passing the fire and cutting off escape. They should not try to operate ahead of rapidly spreading conflagrations or brush fires, particularly on an upgrade. Backfiring may be appropriate, however (Chap. 14).

When another building becomes involved, it is generally from heat radiation, although extension may also be caused by heat conduction, by defects in dividing walls, or by flying sparks and embers. In addition, heated gases may enter a structure through inlets of a duct or air-conditioning system. In rare cases the collapse of the fire building may weaken

other structures and cause fires by electrical short circuits and disrupted heating units.

Units (ladder or other) assigned to check exposed buildings should follow this list:

1. If necessary, search for and remove occupants (see above, Rescue Work).
2. Close windows and inlets to air-conditioning systems that are creating or intensifying an exposure hazard.
3. Vent at the roof and on the unexposed side or sides if feasible.
4. Put out incipient fires, using extinguishers or house lines.
5. Move exposed combustible stock to a safe place.
6. Shut down sprinklers that are operating unnecessarily. Open drain valves. Shut down other duct systems as required.
7. Promptly report on conditions via walkie-talkies or other means and promptly call for necessary assistance.
8. Check for any possible defects in dividing walls, such as inoperative fire doors and abutting beams.
9. Set up spark patrols as required.

Overhauling. Overhauling is the systematic examination of the building and its contents to prevent rekindling, reduce property damage, and detect and safeguard signs of arson. In addition to the responsibility and the right to overhaul, the fire service has a strong moral obligation to see that businesses or homes are safely returned to the owners as soon as possible. Excess overhauling should be avoided. Needless to say, the efficiency of the fire operation has a considerable bearing on the amount of overhauling needed.

Actually, overhauling starts with the first efforts to open up ceilings, partitions, floors, and other structural parts for examination or to hit the fire with a line. This type of opening up is *precontrol* overhauling. After the fire is controlled, *systematic* overhauling begins and the building and its contents are examined. The decision that the fire is under control can be the critical point in the operation, particularly for the officer responsible for finishing up. If the decision is sound, all will be well and men can be rested before final overhauling begins. If, however, the report of control is premature, an unnecessarily heavy burden is placed on the men by such an unsound decision.

As soon as conditions permit and the fire building is accessible, a thorough search of the premises is conducted, including shafts, roof setbacks, yards, and courts, to check for injured or dead persons previously undetected, who may have sought escape by jumping from windows or roofs. Officers should check in closets, under beds, and in any other place where occupants, especially children, might seek refuge in a fire.

A checklist for overhauling follows:

1. Survey the situation so that an efficient plan for overhauling can be formulated. While the plan is being made, firemen can be rested. The plan should specify the work to be done, who is to do it, how it is to be done, and the order in which it is to be done. If possible, arrange apparatus and relieve traffic congestion.

2. Do not jeopardize personnel unnecessarily. The structural stability of the building and affected floors must be checked, gas and electricity shut down if required, necessary ventilation carried out, water drained from floors as required, proper lighting equipment provided, and holes in floors covered or guarded if needed. Constant supervision should be exercised. If the stability of the structure or of a floor is questionable, operations should be conducted from the exterior, using lines from safe vantage points. Officers should see to it that men work as little as

FIG. 11-8. Move contents to a safer location when time permits—and it often does—during overhauling.

possible under heavy machinery or objects, that they have specific assignments, and that they do not wander beyond the range of supervision.

3. Give prime consideration to concealed spaces through which fire may be moving undetected. Attention is then given to other parts of the structure where there may be some fire but no possibility of serious extension.

4. Shut down sprinklers operating unnecessarily, and open drain valves promptly. Keep a man at the control valve as a precaution. Drain the water from the structure, utilizing scuppers, toilet-bowl openings in the floor, broken soil lines, eductors, and pathways provided by sawdust and canvas salvage covers in conjunction with other floor openings.

5. When time permits, move undamaged furniture and similar objects to a safe place before pulling a ceiling for an examination.

6. Use equipment that is less likely to weaken the structure. For example, a saw may be a better tool than an axe in some instances.

7. Remove smoke-producing materials from the building if necessary. If a wetting agent is on hand, removal may not be necessary. However, where heavy baled material such as paper or cotton is involved, it is almost invariably necessary to remove it. It may be feasible to use a hand truck to convey bales to a window, whose sill is removed to the floor. If this is done on more than one floor, select windows in different vertical rows to avoid weakening the structure. Be sure to check the area below before pushing bales out.

8. Clear an appropriate place for an examination of the contents. Undamaged stock should be left on shelving or moved to an area where it will not be affected by further operations. Valuable personal or other property should receive particular attention and should be handled by prescribed regulations.

9. Remove stock before pulling shelving down. Be alert where jugs, carboys and jars are present. The bottoms may drop out and cause serious burns or explosions if contents are hazardous. The same precautions are advisable where dangerous dusts may be thrown into suspension and cause an explosion.

10. Turn over involved material in the cleared space, utilizing bathtubs, barrels, or salvage covers for dipping. Rags and wood should be separated from plaster and debris. Small tips or fog are generally sufficient while overhauling.

11. If heavy objects must be moved, place them near the walls where support is greatest.

12. Safeguard any evidence of arson. Comply with departmental regulations on the procedure to be followed.

13. Do not open up the structure unnecessarily. For example, do not make an opening in the roof to examine the cockloft if it will suffice to remove the returns of the skylight or if the extent of the fire only warrants pulling a small part of the ceiling below.

Officers should be alert to the advantage of using various overhauling jobs to train new men.

Salvage. Salvage work refers to tasks such as covering materials exposed to water dripping from floors above. For many years this work was done by fire-patrol units maintained by fire-insurance organizations, but at present many fire departments perform this work as part of overhauling.

Salvage work can be carried out more efficiently when it is integrated with other phases of fire operations. In addition, the training associated with salvage tends to increase the skill of firemen in forcing entry, overhauling, and applying minimum amounts of water during fire operations. Minimum use of water reduces property damage and lessens the possibility of electric shorts, with their attendant fire hazards. Consequently,

occupants will be deprived of electricity less often. Overall decreased property damage should ultimately be favorably reflected in fire-insurance rates.

Improved efficiency means that interruption of business will be briefer, thereby lessening unemployment. Homes are returned sooner to the occupants, alleviating the need to seek shelter elsewhere, possibly at their own or public expense. These advantages may lighten the tax burden and improve public relations for the fire department.

Finally, salvage service by the fire department eliminates any question of divided responsibility about such important matters as restoring the sprinkler system to service, handling valuables found at fires, and providing for the security of the fire premises after operations are completed.

Salvage by the fire department has some disadvantages. It increases the work load and necessitates carrying more equipment on apparatus; this may reduce efficiency. Additional special training will be required for fire personnel. Salvage work may be delayed indefinitely when there is a life hazard to occupants, and in any event, units will be kept out of service longer, due to the additional duties. *Salvage units* in a fire department will minimize these disadvantages.

There is a problem in drying and repairing salvage covers in quarters, and the space and time required may detract from maintenance of quarters, drill, and inspections (fire prevention, alarm box, and hydrant).

The responsibility of the fire department while carrying out salvage operations is increased over property, valuables, and merchandise, and firemen necessarily operate over wider areas. This entails additional problems of supervision.

Salvage work is done better when handled by fire departments, but such service necessitates higher budgets due to increased quotas and increased cost of training and maintenance. Since improved efficiency is highly desirable, the only question remaining is who will pay the cost. Representatives of interested parties (municipalities and fire-insurance companies) might work out an arrangement that is fair to all.

12

Rescue and Squad Companies

Rescue Companies

Special units such as rescue companies are designed to carry out the special functions implied by their names and not to perform functions normally carried out by engine and ladder companies in extinguishing the ordinary fire. In order to utilize effectively the amount and variety of equipment carried, the recommended minimum complement of a rescue company is six firemen and an officer. Men selected should have a strong desire to do rescue work and should have at least five years' experience, preferably in a busy ladder company; they should be adept mechanically. During recruiting, the personnel cards of all applicants should be checked and those who meet initial requirements should be interviewed and examined. Acceptable recruits should then be given a trial period with an operating rescue company so that they can be tested, trained, and screened under field conditions. Officers should be selected from rescue-company personnel or from among men who qualify for rescue companies and have in addition extensive experience as ladder company officers.

Few training schools are equipped with facilities to train rescue men in shoring, rigging, oxyacetylene cutting, use of jacks on trains and trucks, and other special skills. To overcome this limitation, the cooperation of utility agencies, construction and demolition contractors, transportation companies, and civil defense authorities should be solicited so that their facilities and resources can be used to develop the desired

skills (demolition sites, especially in slum or other clearance projects, provide ideal training grounds and supply wood and scrap metal for use in daily drills in company quarters). An effort should be made to send selected officers to civil defense disaster schools to improve their background and acquaint them with the latest developments in rescue procedures. These officers, in turn, can train other fire personnel. A library of rescue-work material should be available in company quarters.

Training programs should emphasize preplanning and experimentation to encourage the proper selection and skillful use of tools and equipment, whatever the specific problem may be. Standard solutions should be developed for every conceivable problem so that, during operations, definite assignments can be made as quickly as possible for maximum effectiveness. It is helpful if personnel of other units are familiar with special equipment of rescue companies in the event that members of the former are detailed to the latter.

Rescue-company Tools. *Cutting Tools.* This group includes saws for cutting wooden pier decking and double flooring, which may be either gasoline and electric types or chain, circular, and power hand saws of the bayonet type (where smoke impairs visibility, the circular saw may be preferred to the chain type to reduce the chance of injury to personnel); concrete breakers for breaching walls and making openings in concrete flooring over piers and cellars, which are powered by a high-cycle 3,000-watt portable generator and may be used with bull points, chisels, and broad chisel; oxyacetylene cutting torches for cutting bars and metal obstructions at fires or emergencies involving train or vehicular accidents or for cutting metal doors and making openings in the sides of ships (pack sets carried on one's back for small inaccessible jobs and a large commercial set on the hand truck are usually provided); assorted hand saws, axes, and pipe cutters to supplement the power tools; and rotary cutters of various sizes and types to make openings in wooden floors for the operation of distributors or cellar pipes at pier or cellar fires or for draining floors.

Lifting and Pulling Tools. Devices designed for hoisting, bracing, wedging, and similar jobs that may be met at building collapses, railroad or vehicular accidents, or unusual overhauling work are in this category. Jacks include the power type, powered by a hydraulic pump and used with various jacks, spreaders, and extension pieces, and journal jacks, railroad jacks, and hydraulic jacks. A ratchet-type hoisting tool, trench braces, and wedges, rollers, and pry bars are also carried.

Respiratory Devices. Respiratory devices include various types of masks. A self-contained demand-type mask with two spare cylinders is provided for each company member on duty.

First-aid Equipment. A complete medical bag is carried as well as stoke

stretchers, blankets, and wool caps, splints of various kinds, resuscitators, and inhalators. This equipment is used for both firemen and civilians.

Refrigerator Tools. Tools for coping with refrigerator leaks at fires or emergencies include halide detectors and sulfur tapes to detect leaks, plugs and clamps to stop leaks, and assorted wrenches to tighten packing nuts, etc.

Special Extinguishing Agents. Mechanical and chemical foam is carried for use on class B fires and G-1 powder for use on small magnesium-powder fires (Chaps. 3 and 7). Soda ash is for use where muriatic acid or similar acids are involved. Dry chemical and wetting agents are also carried (Chap. 3).

Miscellaneous Equipment. Rubberized suits are carried for use in situations involving ammonia leaks, toxic insecticides, skin absorbents, etc. Rescue companies also carry various kinds of communication devices, of which the sound-powered phone operable with demand-type masks is especially notable. These phones work where other devices may fail, particularly at subway fires. Smoke ejectors are carried for use in ventilating fire areas, particularly those below ground.

Response. Rescue companies should be assigned to respond (1) to all alarms in the vicinity of target hazards within a radius of 2 miles of the fire house, (2) if they can arrive at alarm boxes near their quarters before the nearest ladder company, and (3) to all fires at which all units responding on the first alarm have been utilized.

When rescue companies are not assigned to respond and the fire is under control, it is advisable to put in a special call if their power tools would be particularly helpful in coping with concrete floors, difficult doors, double flooring, etc. A rescue company can handle such jobs with less effort and in less time than several ordinary units working with hand tools. In general, a rescue company should not be used for overhauling, but there may be exceptions where toxic products of combustion are being emitted or where a large supply of masks is needed.

Many members of rescue companies hold Red Cross First Aid Certificates and have considerable skill. Hence, a special call is in order if such skill is required or if it is necessary to handle injured persons in inaccessible locations. In addition, these units have the equipment and experience to handle the removal and limited treatment of persons injured in building collapses and large transportation accidents. A special call is also appropriate when there is a heavier than ordinary refrigerant leak, when weakened structural members need shoring up, or when dangerously hanging signs must be secured.

If a rescue company responds but it is evident that its help is no longer needed to control the fire, it may be advisable in some cases to have it stand by in case first-aid skill and equipment are needed for fire

personnel affected by smoke, exhaustion, eye irritation, cuts, etc. A company operating at a fire where only a limited amount of its equipment is needed can be available by radio to be called elsewhere if needed, leaving one or two men to continue operating the equipment in use.

Advantages. Rescue units are able to force strong locks and doors under difficult conditions because of their large complement of men, adequate masks, special cutting and forcing equipment, and experience in forcing entry. Rescue-company personnel are trained in various phases of rescue work: use of lines, ventilation, efforts to reach trapped occupants, search and removal of victims, and rendering first aid. The manpower available makes it more possible to vent and advance lines simultaneously, thereby increasing chances of success. Moreover, the availability of reflective and rubberized suits enables rescue companies to make a more extended search for victims in unusual fire conditions or other hazardous situations.

In addition to their ability to ventilate structures under difficult conditions, rescue companies can improve the smoke condition, both during and after the fire, with the mechanical ventilating equipment they carry. Their concrete breakers can ventilate cellars when no other means is effective. Rescue companies, fully masked, can be used to relieve units on lines and to press forward to quick extinguishment. Reflective or rubberized suits may help even more. Where heavy wooden flooring is an obstruction, rotary cutters may facilitate the use of distributors and cellar pipes. Concrete breakers can help breach walls. Thus, fires otherwise inaccessible may be brought within the range of operating lines. At fires where water cannot be used to extinguish, it may be possible for rescue companies to provide and apply an effective agent.

Ordinarily, rescue companies are not used for overhauling. However, where charred beams must be exposed and concrete is in the way or when a considerable amount of double flooring must be cut, the power tools of the rescue company can do a quicker job. Rescue companies are particularly adapted for securing dangerous overhead objects such as cornices and signs, so that finishing-up operations are made safer. The wetting agents carried on rescue apparatus can be used to make overhauling more efficient.

Rescue companies, because of their training and their resuscitator apparatus, are particularly valuable at subway or similar fires where many people require first aid for smoke inhalation. In such cases, it may be advisable to call all available rescue units rather than transmit greater alarms, which will bring many unnecessary pumping units. The communicating devices carried by rescue companies help not only in rescue work but also in transmitting information to the commanding officer so that he can understand his problem and take appropriate steps more

quickly. This can be an important factor if it is unusually difficult to locate the fire and determine its extent.

A distinct advantage is that rescue-company personnel have above-average qualifications and training. Their high morale is invariably translated into efficient work at fires or emergencies. Perhaps in no other operation do rescue units show to greater advantage than working at building collapses. In this field, they are ideally prepared.

Squad Units

These units were organized in some departments to ensure adequate manpower in the vital early stages of fire operations and to lighten the work load of companies in high-fire-incidence areas. The recommended minimum complement of a squad unit is an officer and five men. The units are used to furnish added manpower where and when conditions warrant, to relieve men affected at fires by smoke, heat, and injuries, to help with work ordinarily done by engine or ladder companies except overhauling, and to supply additional masks and cylinders.

The personnel of squad companies is selected with care, since members must be equally skillful in ladder- and engine-company work. Leadership and morale in these units have been high. As a result, the record made by squad units in a short time is an exceptional one.

In carrying out their assignments at fires, squad units operate like engine or ladder companies (Chaps. 10 and 11). When the services of the squad are not needed, it should return to quarters as quickly as possible and hold itself available to respond to subsequent alarms at which depleted assignments may be rolling in. The greatest advantage of a squad company at a fire is that the extra manpower permits many jobs, especially rescue work, to be accomplished more quickly; the fire is more quickly under control. This has many derivative advantages: the work load of all fire personnel is lightened and the possibility of injuries reduced; direct and indirect fire losses will be lessened; there will be less need for additional alarms; overall fire protection will be improved, because areas are not stripped of adequate fire protection as often and also because all units will in general be returned to quarters more quickly. The squad unit fills a long-standing need at fire operations: the need for more men rather than more apparatus.

13

Equipment and Apparatus

Equipment

Equipment used with extinguishing agents, such as master-stream appliances, nozzles, and applicators, have been mentioned previously. This discussion is restricted to new equipment or relatively new improvements in standard (and other) equipment as they may affect firefighting.

Breathing Equipment. Breathing equipment has been improved recently both quantitatively and qualitatively. Many departments now have a mask for each man on the apparatus; some have a filter mask for each man working plus two demand-type masks for each company, which are for situations in which filter masks are inadequate. Demand-type masks have been improved to make it possible to keep in contact with the wearer by speaking diaphragms or sound-powered telephone and to warn the wearer, by a bell, when cylinders are about used up.

The all-service canister has been improved by the use of a new desiccant that is more effective, reduces problems caused by moisture, and will not gel or harden. It also lowers breathing resistance in the canister, This canister, the S type, now has a window indicator that more accurately indicates the moisture content and the acidity of the canister ingredients. Some face pieces used with such canisters have speaking diaphragms. The H type of canister is the same as the S type except that a higher-efficiency filter is used to protect against radioactive particles, beryllium dusts and fumes, living organisms, and extremely finely divided particulate matter. It is mandatory to know and keep in mind

the limitations of canister-type masks so that they will never be employed in situations that warrant the use of demand-type masks. Exclusive use of the latter is recommended by the author.

In addition to masks, which prevent firemen from being overcome by smoke or toxic gases, mechanical means of resuscitation and artificial respiration (particularly mouth-to-mouth breathing) are available for both firemen and occupants that may be overcome by smoke inhalation or that may have difficulty in breathing because of some other condition.

Pnealator. The pnealator is an automatic artificial respirator; it requires no manual assistance. It exerts positive pressure only: it inflates the lungs to a predetermined pressure (7 oz per square inch); then the pressure is cut off and exhalation results from the natural recoil of the chest and diaphragm. The automatic breathing action of the pnealator continues until the victim resumes breathing on his own; then, after some adjustment, the pnealator can be used as an inhalator.

Inhalator. The inhalator supplies a gentle constant flow of oxygen. If the victim is unconscious, he will receive no gas unless artificial respiration is rendered. When the patient starts to breathe, artificial respiration should be discontinued and the inhalator used as long as necessary. The breathing bag attached to this device is filled with gas when the control valve is opened and should be kept partly filled at all times and carefully watched for indications of the victim's rate and depth of breathing. Inhalators are frequently used in cases involving respiratory failure.

Resuscitator. The resuscitator is an automatic artificial respirator. In operation, it produces alternate positive (5 oz per square inch) and negative (3 oz per square inch) lung pressure. These pressures are reached only momentarily at the peaks of the cycle, and both practical experience and medical observation have shown them to be safe, with no injury to person or lungs. The resuscitator can be switched to operate as an inhalator when the patient begins to breathe. A rhythmic clicking is heard while the resuscitator is working, and this serves as an excellent indication of progress: regular clicking at about the normal breathing rate indicates that the instrument is breathing for the victim; rapid clicking with no chest movement indicates incorrect position of head or neck or a throat obstruction, which must be corrected immediately; irregular clicking means that the patient has started to breathe; no clicking means a mechanical defect, an empty cylinder, or a leak.

Pnealators or resuscitators are of great value where many people require treatment after being subjected to smoke. These machines do the job well and with minimum manpower.

Aspirator. The aspirator is a device designed to clear airways of mucus so that pnealators, resuscitators, or inhalators can work effectively. It consists of an airway, tube, and bottle. An aspirator is part of pnealator

and resuscitator equipment. A recently developed instrument combines the pnealator, the resuscitator, the inhalator, and the aspirator all in one.

Communication Equipment for Use at Fires. *Radio.* In some departments, every apparatus is provided with two-way radio equipment. This has many advantages: manpower and equipment can be utilized more efficiently, summoned more quickly, and contacted on route to a fire and directed how to approach and where to report. Helpful briefing about the fire situation can be given while a unit is still in quarters and while it is responding. Telegraph signals in some cases alert units about a possible response. In some departments, there are receiving sets in the quarters of chief officers to keep them posted on developments.

Radio-equipped apparatus are constantly "in touch"; hence they can be rerouted quickly. Departments can carry on more extensive fire-prevention programs since apparatus can be readily contacted for fire duty. More frequent inspections of fire-alarm boxes and hydrants are also possible, and improved maintenance will have a favorable effect on alarm transmission and on fire operations.

Battery-operated radio transmitters can be used for rescue purposes, as the beep sound can indicate the location of buried persons.

Powered Megaphones. These devices can be used effectively by chief officers, as they increase the range of the human voice considerably. They can also be used at training schools and in some phases of fire-prevention work.

Public-address Systems. Public-address systems fitted with directional loudspeakers can be used at school fires to give necessary directions to teachers and students. Such a system can also prove extremely valuable in reducing panic at fires (on ships, in subways, and in department stores) where crowds of people are involved.

Parabolic Reflector Microphones. These may be used to pick up sounds originating several hundred feet away and also to permit communication from the fire to field headquarters.

Portable Radiotelephone Pack Sets. These are probably the most common means of communicating between the commanding officer and subordinate officers. They are lightweight (about 11 lb), compact, simple to operate, dependable, and have a good range (2 to 3 miles). At subway fires, these sets may be inerted by shielding (dead spots).

Sound-powered Phones. These phones can be used with face pieces of some demand-type masks. Their great advantage is that the mask need not be removed while the phone is operating, a big advantage when smoke condition is severe. The phones are connected by 200-ft cables, and care should be taken to use sufficient cables. These phones are not affected by shielding.

Miscellaneous Signals. Some departments communicate by hand or light signals, and even by the number of tugs on a rope.

Television. Television has been experimented with and found satisfactory as a method for surveying the overall situation. A light commercial camera and receiver are used: the camera in a helicopter and the receiver at field headquarters.

Telephone. Advanced techniques for laying telephone cable by helicopter permit laying a newly developed multichannel telephone cable at speeds up to 100 mph. A compact package, hooked under a standard Army helicopter, carries 10 miles of telephone cable packed in zigzag fashion to prevent snagging at high speeds. Dropped from a fast-moving helicopter, the cable can span bodies of water and previously impassable terrain to provide vital communication between field headquarters and subordinate officers or fire-service units. This technique is especially suitable in large scale brush or forest fires or in flood or disaster areas.

Helicopters. Helicopters can assist communications by laying telephone cable, by carrying out reconnaissance and liaison, and, of course, by transporting men and equipment. The helicopter is particularly useful for reconnaisance. The commanding officer can circle a large involved area rapidly, plan strategy and assign activities more quickly, and keep abreast of changes and make necessary modifications in plans promptly.

Special Communication Units. Some departments have these units, which are either generally assigned to respond to greater-alarm fires or specially called as needed. Apparatus may be equipped with a land-line telephone, two-way radio, mobile pack-set operators, and a mixer panel for the receipt of pack-set messages. A communications unit provides an excellent field headquarters and can help substantially to coordinate fire operations.

Photographic Equipment. Some fire departments have photography units, which can be used to advantage at fires and elsewhere. If a unit is strategically located, it can be on hand early in the operation. The resulting pictures will be more timely and practical for the purposes of improving public relations, training firefighters, and providing legal evidence. The public might understand better the problems confronting the fire department in the crucial early stages of an operation if pictures taken at that time were available.

For training purposes, the motion-picture camera can reproduce a fire operation practically from start to finish. A motion-picture film is an ideal means of appraising the performance of units at fires. It can also be shown in training schools to demonstrate how tools should be used, how procedures should be followed, how apparatus should be placed, how companies should report in at fire operations, etc. Photography can be helpful where arson is suspected, as investigation and prosecution will

be facilitated if pictures can establish guilt. Photography can also provide testimony in cases of accidents to apparatus and members and in cases of meritorious acts.

Probably there is no more effective way to depict safe and unsafe acts and conditions than by photography. This can be utilized at fire operations and in fire-prevention activities. Much could be accomplished if brief pictures were shown on television and in motion-picture theaters of the proper way to transmit a fire alarm, the possibly disastrous results of a false alarm, the many ways in which human carelessness magnifies the fire hazard, etc. Motion pictures are an effective medium for educating school children about fire drills and fire prevention.

Photographic reproduction can also be used in fire-service administration: personnel records and inventories of real estate, apparatus, and equipment can be kept on microfilm.

The Peeping Tom camera is a military development that might be of use in coping with fires after a bombing attack, since this camera has a lens that can cut through 20 miles of haze. It is mounted on a tripod and can be carried and operated by two men.

The Photoscan system makes it possible to transmit photographs from aircraft to ground stations with no loss of detail. This is a sizable advance in aerial reconnaisance and could help the fire service where large areas are involved, such as at brush fires or wartime fires. Pictures could be relayed hundreds of miles in seconds, and units in communities joined together in a mutual-aid program could be quickly alerted and advised on a situation that required cooperation. The system weighs about 70 lb. It is best suited for conventional photographs, but it can also be used to transmit filmed data recorded by infrared, radar, or sonar equipment.

Tools. *Electric-powered.* Power for this equipment is obtained from built-in generators on apparatus, from portable generators carried on apparatus, or from public or private utility sources. Where power is taken from a public system, such as a lamppost on a highway, a specially arranged hookup may be required. The generators used may have a capacity of 3,000 watts. This can supply concrete breakers; chain, circular, and bayonet-type hack saws, which are particularly advantageous at aircraft and transportation fires; circular cutters, which assist in ventilation and make openings through which cellar pipes and distributors may be operated, and augurs, which help drainage.

The electrically controlled ladder pipe is now a reality. The control panel is mounted on the aerial turntable pedestal, within reach of the man operating the ladder. Two weatherproof motors are located on the ladder-pipe assembly and are connected to the control panel by means of a heavy-duty cable. By manipulating the two buttons at the control panel, the operator can easily and quickly control the stream operation and the shape of the nozzle pattern from 90° fog to straight stream.

Hydraulic-powered. This group includes hydraulic jacks, remote controls for master-stream appliances, and modern aerial ladders. Some hydraulic jacks power a ram and special attachments for pulling, spreading, and clamping, with capacities up to 20 tons; in specially made rescue kits, the capacity may be 50 tons. Heavy-duty hydraulic jacks have capacities of 100 tons. Some apparatus have central pneumatic compressors built in to supply power to saws, drills, and jacks.

Ladder pipes can be controlled both electrically and hydraulically. Most modern aerials are operated by hydraulic power, and this accounts in large measure for the superiority of such ladders in rescue work, ventilation, and the use of hose lines (Chap. 9).

Protective Clothing. Especially designed suits enable firemen to walk through flame and are invaluable for rescue work at airplane crash fires. The wearer cannot always carry victims out with him immediately, but he can advance closer to the fire with an extinguishing agent and apply it with maximum effectiveness, thereby increasing the chances of survival for trapped passengers. Some aluminized garments offer amazing protection against radiated heat, protecting the wearer by reflection rather than insulation. Such a garment enables the wearer to approach and shut or open valves in an area subject to a high level of radiated heat. This could well be the turning point in a class B fire, where numerous tanks with highly flammable contents might be exposed. Such clothing is referred to as *approach, proximity,* or *fire-entry suits.*

Reflective stripes are used on fire apparatus and on helmets and turnout coats of fire personnel to make apparatus stand out more noticeably at night, thereby minimizing the number and severity of accidents, and to enable fire personnel to maintain better contact at night operations and more quickly to find personnel not accounted for.

Plexiglass eyepieces are very effective protection for the eyes of firefighters. Many apparatus are provided with safety straps for the officer and chauffeur. A hose strap has also been developed, which enables the user to cope more safely and effectively with sudden and unexpected surges of pressure at the nozzle.

Hose. Much effort has been expended to develop the ideal hose. There have been definite improvements in weight, flexibility, compactness, drying capacity, and reduced turning, warping, and rising of hose under pressure.

Leading hose manufacturers have developed a lightweight product with synthetic fiber. This has many advantages: hose can be stretched faster; lines can be stretched with fewer men; extinguishment is quicker, with less water and fire damage; less energy and time are required to replace hose on apparatus and to hang it in drying towers; units will be ready for service more quickly.

More flexible hose is easier to handle when being stretched or placed

on apparatus. Improvements in weaving have minimized the tendency to kink, seen in some cases when synthetics originally came into use. This improvement, in turn, reduces the possibility of bursts in the line.

Hose that is more compact can be stored and carried in greater quantity in the same amount of space taken up by bulkier, more rigid hose; hence more hose will be available from each apparatus, more lines can be stretched from the pumper near the fire, rolled-up lengths of hose are prepared easily and can be carried more easily, and the control and extinguishment of the fire is facilitated.

Some newer types of hose are treated to practically eliminate mildew. They are also readily cleaned in automatic hose washers and dried in electric dryers. These advantages tend to prolong the useful life of hose. Reduced turning, warping, and rising of hose under pressure ensures greater dependability during use. Time and experience may show that heavy and light hose can be used to advantage in combination, the former outside, where rougher usage may be encountered, and the latter inside the fire structure, where maneuverability may be a prime factor.

Miscellaneous. Some important improvements have been made in tools for forcible entry and overhauling. A simple nail puller adapted to facilitate removal of lock cylinders has proved effective and less damaging on most types of doors. There have also been improvements in hooks designed to pull ceilings. Special mention should be made of explosimeters and eductors. Explosimeters make it possible to determine whether a gas is within or near its explosive limits. Without such a device, officers investigating "an odor of gas" are at a loss. The eductor, while not exactly a recent development, is an important one. It simplifies the dewatering process at levels and in areas otherwise beyond the capacity of apparatus pumps because of high lift or inaccessibility.

Apparatus

There have been some outstanding improvements: (1) practically all apparatus are equipped with two-way radio; (2) many types have multiple uses; (3) more types have booster equipment; (4) newer apparatus have built-in power generators; (5) they have enclosed cabs.

Placement of apparatus at fires should receive prime consideration since one poorly placed apparatus, especially in the early stages of the operation, can be a severe handicap, nullifying its own usefulness as well as that of other units. Officers first on the scene should be alert to this possibility. An error in selecting a hydrant can be fatal. Hence, ladder companies should not block engine companies from needed hydrants; the latter, when hooking up to hydrants, should make every effort to leave a passageway for other apparatus.

Numerous possible conditions make it difficult to set up hard and fast rules. The problem can be simplified to some extent, however, if it is feasible to keep chiefs', squad, and rescue vehicles out of the fire street. It will also help if approaching units can be directed by radio. For example, if a corner building is involved, the ladder company second to arrive should, in most cases, be informed to place their apparatus in front of the uncovered side.

Pumpers. The trend in comparatively recent years has been almost exclusively toward the centrifugal pump. However, with the advent of the high-pressure method of water fog production, the piston pump is again in the picture. Requirements of high pressure likewise brought about some new designs in centrifugal pumps.

FIG. 13-1. The bane of a commanding officer is poorly placed apparatus. Note the pointless position of the aerial, the unused hydrant, and so on.

Gas-turbine-driven pumps can deliver many gallons of water per minute at fewer weight pounds per horsepower. The weight-to-power ratio is much lower than that of comparable reciprocating engines. The gas-turbine pump can be used to pump water from the original source or to relay water, can be operated at low cost and on less flammable diesel fuel, can be readily started at low temperatures, and can be easily maintained and simply operated. It can be transported in helicopters and hence finds much favor in mountainous areas subject to brush and forest fires.

The application of large-scale pumping units with capacities as high as 3,000 gal per minute has been tried. This effort is possibly influenced by the development of master-stream appliances, with their high discharge rates, but it is also in line with the idea that better use should be made of water supplies near the fire.

Many pumpers today have built-in systems, some of which are dual-

purpose, that permit the use of either foam or wetting agents. In addition, the connections from the pump to the turret pipes are more efficiently arranged. Some pumpers are so designed that a high-pressure pump has its own power takeoff coupled to the engine so that fog lines can be operated while the truck is in motion fighting grass and brush fires. If such a pumper is equipped with 500-gal water tanks, it can operate well at many structural fires. In fact, this type of apparatus is one of the main reasons why the fire service has been able to cope thus far with the ever-increasing problems caused by the spread of industry and civilians toward suburban areas. The need to deal successfully with these problems is reflected in the more recently designed suction and discharge connections. The former are now found on the front and rear as well as on the sides, and the latter may be found at the rear and top; all valves for the remote gates are controlled from the operator's panel. The 2½-in. suction connection equipped with gate valves expedites the fast attack featuring the use of preconnected 1½-in. hose and, quite frequently, the relaying of water in what may be referred to as in-line pumping. While waiting for water from the hydrant or relaying pumper, the unit can use the water in the booster tank with maximum effect.

Improvements in valve design, automation, and exterior design have also contributed to the progress of the modern fire service.

A comparatively recent development is the reappearance of the single-stage pump. It has important advantages: simplicity of operation, minimum internal power loss, and a high-rating performance at engine pressures up to 300 psi.

Modern Aerial Trucks. The trend from wooden to metal aerial ladders has gained momentum during recent years.

Advantages. The length of some modern aerial trucks is only slightly more than that of a conventional pumper; other types are a little over 50 ft long. Smaller quarters will suffice for some, with reduced maintenance costs. Other units may be housed in quarters where metal aerial trucks replace the wooden type. This facilitates the consolidation of units, which is usually desirable. The shorter truck gets out of quarters more easily and quickly, is more maneuverable, has fewer accidents, causes fewer injuries, deaths, and lawsuits, arrives at the fire more often, and causes less obstruction at fires. The danger from overhanging ladders, which caused many accidents, has been eliminated.

The physical characteristics of modern aerial trucks are advantageous: the elastic limit (in pounds per square inch at 75°F) for wood, aluminum, and steel is, respectively, 8,000, 35,000 and 52,000. The tensile strength for wood, aluminum, and steel is, respectively, 11,000, 60,000, and 72,000. Apparatus manuals state that eight to ten men can be carried on some metal ladders. This is considerably more than wooden aerials can carry. Acceptance tests for metal ladders are much more stringent.

In addition, they must pass nozzle-reaction tests and a retraction test that spring-hoist wooden aerials could scarcely pass. Metal aerials are equally strong in tension and compression. When extended and used, in this respect they are superior to wooden aerials. Metal aerials have more uniform strength. Wooden aerials require the use of truss rods, reinforcement channels, protecting strips, and other metal parts. Since metal and wood have different characteristics of expansion and contraction, a stable structure with such parts is more difficult to build and maintain. Metal aerials are not subject to dry rot or splintering, and they are less subject to fatigue and loosening at joints.

Guard rails to the top of the aerial enable fire personnel to carry out rescue assignments with greater safety to themselves as well as to those being rescued and also to stretch or operate lines from aerials with greater safety and efficiency. Rubber-covered rungs minimize slipping. There can be no accidental kickoff. Because of the greater strength of metal aerials, there is less possibility of collapse when they are overcrowded, as sometimes happens at greater-alarm fires. The metal aerial will not exceed the perpendicular, and its stability in high winds is better. Automatic devices prevent overextension at low elevations, and a strain gage indicates when the ladder is being overloaded. Automatic plumbing devices correct road crown or grade. Automatic devices stop the ladder if it hits an obstruction while being raised, lowered, or extended.

Ladder pipe can be controlled from the turntable by hydraulic or electric controls. This eliminates the need to have a fireman operate the pipe from a position on the aerial under possibly dangerous conditions. Metal aerial trucks are so designed that it is no longer necessary for members to ride to and from fires on runningboards paralleling the ladders. Men are now better protected against inclement weather and injuries from accidents with other vehicles.

At fires, metal aerials are better at lower floors. For example, the 30-ft bed ladder can be used effectively at third-floor levels. This is not the case with wooden aerials because their bed ladders are longer (about 45 and 40 ft, respectively, for the 85- and 75-ft types); these ladders would reach the third floor, of course, but the angle would be very bad. The metal aerial can be used at a better angle, and it has the additional advantage of guard rails. When a ladder is placed in a window at, say, a 37-ft level, the 85-ft and 75-ft wooden aerial should be placed with the center of the turntable at least 34 and 25 ft, respectively, from the building line so that the bed ladder will not overshoot the mark. Metal aerials with 30-ft bed ladders do not have this problem. Because of the shorter bed ladder and power propulsion, metal aerials have an advantage when overhead obstructions, such as wires, lampposts, and tree limbs, are met. They have better propulsion to ventilate by breaking windows. Two lad-

der pipes can be operated from metal aerials and only one from wooden aerials; metal aerials can withstand higher nozzle reaction. They will not ignite and burn, and they cause less obstruction to other apparatus at fires due to better positioning and shorter length.

Metal aerials can be operated by one man, a considerable advantage, particularly if four men would otherwise be needed to raise a 35-ft portable wooden ladder. They can reach much higher than wooden aerials in many cases.

Disadvantages. The width at the rear mudguard and rear step increases the likelihood of accident. This disadvantage is aggravated by the fact that the visibility of the tillerman is impaired by the width of the truck at the top rear area. Tillermen sometimes use various and dangerous means (including removal of safety strap) to elevate their position and improve visibility. Some tiller seats are too springy, and as a result, the tillerman is bounced around too much, even on paved streets; other seats are too small, particularly in the winter when heavy clothing is worn. In some cases, the control pedestal on the platform impairs the visibility of the chauffeur when backing up the apparatus.

Motor failure practically renders the metal aerial ladder useless for fire operations. Duraluminum metal loses about 50 per cent of its tensile strength at 375°F; between 400 and 600°F, aluminum alloys lose about 50 per cent of their ultimate strength (commonly expressed in pounds per square inch, this is the maximum stress that can be developed in a material as determined by cross section of original specimen). Their strength decreases continuously as the temperature continues to rise. Metal aerials are subject to galvanic corrosion from rainwater, water received at fires, or condensation containing chlorides or salts. Even water passing over one metal and dripping or running onto another can cause this harmful corrosion. Aluminum is more vulnerable in this connection than any other common metal except magnesium and zinc.

Tormentors (metal supports extended from the side of the truck below the aerial ladder platform, and adjusted in position to carry part of the extra weight imposed at that point when the aerial is raised) are awkward on some types of trucks and take too much time to put into place.

Jackknifing of the truck is advocated for some types. This cannot be done in some instances because of street conditions and the presence of other apparatus, and hence the advantages are lost; where the truck can be jackknifed, it can readily interfere with the passage or placement of other apparatus.

The high guard rail on some aerials makes it difficult and even dangerous to step from the ladder to a roof when the tip of the aerial is extended too much. This is particularly noticeable when a man is carrying a tool or portable communicating device and wearing a mask. To remedy this difficulty, it is advisable to raise the aerial only a foot or so above the

roof so that men can continue straight over the top rung rather than having to climb over the guard rail. If a fly ladder with such a guard rail is placed at an oblique angle into the ordinary residential window, it is extremely difficult for firemen to enter from the ladder or remove a person through the window onto the ladder.

The foot space on the rungs of some aerials is limited, and this slows up ascent, especially when men are wearing boots. Working space on platforms is too restricted on some types. Care must be continually exercised, even during drills, to see that members do not inadvertently step off the platform and injure themselves.

The metal aerial ladder is here to stay. The advantages far outweigh the disadvantages. Moreover, many of the disadvantages will be eliminated with further improvements.

The Snorkel. This is a very significant addition to fire-service apparatus. It features well-controlled placement of a platform by means of a boom that may reach 50, 65, or 85 ft, depending upon the model. The capacity of the platform in any boom position is about 1,000 lb (the weight of four men plus three or four rolled-up lengths of hose or other equipment). A built-in 3½-in. water supply to the deck pipe on the platform assures prompt application of water, and a ground-to-platform communications system facilitates coordination.

Another feature is maneuverability: it can rotate 360° from ground level to full extent; in addition, it can be moved around the fire building within a few minutes because it is equipped with quick-acting hydraulic jacks. The snorkel is considerably shorter than many aerial ladder trucks.

Fog or solid streams are readily available from the deck pipe on the platform (or basket) and can be operated with great accuracy in windows or other openings due to the flexibility and maneuverability of the boom and the apparatus. A dual-control feature enables either the operator in the basket or the one at the base of the boom to swing the boom back and forth or up and down. When turret pipes are no longer needed, rolled-up lengths can be carried to upper levels via the basket and hooked up to and stretched from the outlet ordinarily used for the turret pipe. This is a faster and easier way (with less hose and manpower required) to operate, to overhaul, and to take up.

Since it can be used to get a stream into operation quickly and accurately, and since these lines may be needed to protect trapped occupants, the snorkel can help in rescue work. In addition, it can be used for quick ventilation, entry, and search for occupants. The snorkel basket is especially advantageous for the removal of persons overcome or otherwise unable to help themselves and firemen engaged in the rescue work, or for a building collapse, when the debris has to be surveyed and searched for trapped and buried persons.

The snorkel can facilitate ventilation, since men are able to ventilate a

roof without getting out of the basket. This could be an invaluable advantage where roof ventilation by other means is extremely dangerous, for example, at some fires in churches and supermarkets or where the extent of the fire generally makes roof work dangerous. Where there is unusual difficulty in venting due to metal shutters or in windowless buildings, power tools may be used effectively from the platform of the snorkel. At a ship fire, the platform might provide a vantage point from which to operate cutting torches and open the side of the involved vessel.

Overhauling can be facilitated by taking the finishing-up lines off the platform deck-pipe supply outlet. In addition, the basket provides an easy way to transport heavy power tools that may be required for overhauling.

The snorkel has many and important advantages, which in time may become even greater. However, a constant watch must be kept over the men in the basket so that they are not endangered by flame, heat, or smoke. The communication system should always be in use, and where advisable, a line should be ready to cover the platform.

Miscellaneous. Modern apparatus is characterized by versatility, speed, economical use of manpower, increased safety, and greater capacity. Included in this group are rescue-company trucks, quad and quint apparatus, and the modern fireboat. In addition, there are apparatus especially designed to carry and operate master-stream appliances; communications units (see above, Special Communication Units); mask-service apparatus to replenish the mask supply during operations; welfare-service apparatus, such as ambulances, oxygen-therapy unit, and coffee wagons; photography units (see above, Photographic Equipment); and supervising engineer service units, which carry personnel assigned to check water supply on mains, selection of hydrants, the manner in which pumps are being used, etc.

Helicopters can transport portable pumps, hose, water for firefighting purposes, communications lines (see above, Helicopters), and helitankers. Helitankers are water tanks fitted with small pump, lightweight hose, and adjustable nozzle. They have been used in fighting brush fires.

Breakers for fighting brush fires carry water tanks and pumps. They have 10-ton winches in front with 200 ft of $\frac{5}{8}$-in. cable, and they have a prowlike arrangement in front designed to push over fairly sizeable trees and break the way.

Modern apparatus is being improved at an impressive rate. More apparatus is equipped with booster equipment. More hose wagons are provided with pumps. The selection of appropriate apparatus is a most important matter and should be based on the particular problems of the community. For instance, in hilly areas, aerial trucks should have self-balancing turntables.

14

Unusual Fires

The usual fire is one that involves a structure and is put out by ordinary firefighting activities, such as forcible entry, ventilation, use of hose lines, overhauling, and salvage. In unusual fires, any of the ordinary activities may be almost unnecessary or, on the other hand, may play an outstandingly important part. For example, extinguishing a fire in a subway may be a simple matter, but rescue work becomes exceptionally important. Operations at grass and brush fires may not include forcible entry, ventilation, or overhauling but may present other problems, such as establishing firebreaks, relaying water, and discharging extinguishing agents from planes.

In any case, the officer can ascertain and evaluate the problems by following the usual approach of deciding (1) upon the correct objective and (2) upon the activities that will achieve the objective, while (3) noting the presence of pertinent factors and assessing their effects.

As for solving the problems, the same group of principles governing ventilation, placement and use of lines, etc., apply whether the fire is considered to be usual or unusual. Variations in application dictated by the prevailing conditions are always in order. Grass and brush fires, class B fires, and subway fires, generally considered unusual, will be discussed to illustrate the foregoing points.

Arson will also be treated in this chapter because of its relationship to fires frequently classified as unusual.

Grass and Brush Fires. There are three kinds of fires in grass and brushwood: the *surface fire* that burns dry grass and young trees, the

ground or bog fire that starts as a surface fire and then burns downward into the soft spongy ground, and the *crown fire* that involves the tops of trees and is carried onward by convection, radiation, and conduction. Bog fires have been known to burn underground for days. The surface and crown types have several features in common. Both may spread with great rapidity and encompass large areas, and therefore they present problems associated with fires of large perimeter. Operations are frequently hampered by water shortage and serious injuries, and fatalities are not altogether rare. Despite the open-air aspects of these operations, considerable labor and punishment are often the lot of firefighters. In addition, there may be much wear and tear on apparatus.

The ordinary surface fire may be extinguished by lines stretched from pumpers hooked up to hydrants where the latter are available and advantageous to use. Lines from booster tanks and pumps are particularly effective in such cases, and effectiveness is increased if wetting agents are used. Such efforts can be supplemented, if necessary, by sprinkler cans, manually operated portable pumps, and brooms. It has been estimated that a man with 4 gal of water used sparingly and followed by another man with a broom can extinguish fire in an area about 14 ft square. These supplemental devices are more appropriate for minor situations.

At the more serious surface fire, the commanding officer is confronted with many of the problems generally associated with structural fires. He has to survey the area to ascertain the problems and determine the order in which they are to be covered, he has to plan and set up an effective operation, he must summon additional help if it is needed, and he must constantly be alert to the hazard of his men being trapped by the fast-moving fire. If there is a life hazard, rescue work takes precedence as usual. Endangered persons must be warned and evacuated and protected by hose streams if required. Providing covering lines and protecting exposed buildings may be made very difficult if the water supply is poor.

The principles governing the placement and use of hose lines (Chap. 10) apply to all types of fires, including grass and brush. Accordingly, when occupants of a structure are endangered by grass or brush fires, the first line or as many of the available lines as necessary will be stretched and operated to cover the life hazard until rescue is effected. Likewise, during efforts to extinguish where no life hazard exists for occupants, lines should be placed and operated to minimize possibilities of extension while trying to put the fire out, just as in operating at a structural fire.

A notable feature of grass- and brush-fire operations is the comparatively inconspicuous role of forcible entry, ventilation, and overhauling. At the more serious fires, severe problems of rescue work, placing and

using hose lines, communications, getting adequate help (manpower and equipment), supervising personnel, and protecting exposures may be present. The reader, at this point, can ascertain what the crucial factors are and what problems they create.

Fire does not gain much headway on the windward side of the fire; therefore, where life or exposure hazard is not present, most of the fire force can be concentrated on the lee flank of the fire and utilized to head the fire toward a road, creek, clearing, or other barrier. This increases the chances of working toward the front of the fire with greater safety and effectiveness.

At a large fire in a meadow or field, it may be necessary to get ahead of the fire and resort to backfiring. The commanding officer seeks an open space and starts another fire on the lee side of the main fire, which may die out when it reaches the burned-over area of the second fire. In using this technique, steps should be taken to prevent fires developing on the lee side of the barrier by flying embers.

Bog fires may occur where the ground is soft and spongy as in a drained swamp. The fire may start in brush and work its way underground. Operations in such cases may be long and drawn out and may involve injecting water through nozzles inserted into the ground at the numerous hot spots invariably present. The use of wetting agents expedites control.

Crown fires usually start at ground level, work their way up, and spread rapidly when sufficiently susceptible tree growth is exposed. Many of these fires are extremely difficult to control. The major problem is to get enough water on the fire. A more satisfactory solution may be the spread of ABC dry chemical or water mixed with sodium and calcium borates from airplanes or vapors from airplanes, as suggested in Chap. 8.

Class B Fires. These fires are unusual because forcible entry, ventilation, and overhauling are not employed in the usual manner. However, there can be extremely severe problems of selecting the proper extinguishing agent, applying it effectively, and supervising fire personnel to prevent injuries (Chap. 9). In some cases, there may be problems of rescue work, protecting exposures, getting required help (personnel, apparatus, and equipment), and maintaining communications.

In addition to carrying out procedures that are considered usual at fires of serious magnitude (setting up field headquarters, establishing communications, summoning needed help, etc.) the officer in command should consider that the plant personnel familiar with the fire-protection setup in the involved premises may be able to furnish important information about the burning characteristics of the flammable liquids involved in, and endangered by, the fire. This will reveal the type of extinguishing agent and method to be used as well as the possibility of a boilover or

slopover (see Chap. 4). If the fire involves crude oil and has been in progress more than thirty minutes, it may be preferable to start pumping out rather than using foam. If the tank contains crude oil susceptible to a heat wave, it may be assumed that a wave has developed and is of slopover depth; the immediate use of foam hastens the slopover. The officer should also consider the facilities available (fixed systems) to control and extinguish the fire as well as to pump out the contents of the involved and exposed tanks.

Plain hose streams used against the exterior of the tank shell above the level of the burning liquid, allowing water to enter the tank very sparingly—not enough to cause a slopover—may be effective. This is appropriate on a large crude-oil tank that is almost full when there is delay in getting adequate foam equipment and when air agitation is not feasible. This action may retard the development of the heat wave to the extent that when foam is used, a slopover will not occur. However, if boilover or slopover is anticipated, fire personnel should be removed to safe positions.

The presence of dikes is no insurance against spread of fire when boilover occurs. Where the terrain is favorable, the trend is to channel liquid to an area where spillage will not ignite and fires can be extinguished or allowed to burn out as harmlessly as possible. Diversion dikes may be necessary to direct a flow to open depressions, ditches, or closed drainage systems.

Petroleum products are made for specific purposes, and they burn in a definite manner to accomplish the ends for which they are designed. To extinguish fires in these products, it is necessary to alter the fire conditions so that the products will no longer burn. Hence it is important to get information about burning characteristics. The flammable range of the material indicates the proportion of vapors or gases necessary to form flammable mixtures with air or oxygen. The flammable range for petroleum liquid products in general is 1 to 6 volumes per cent of vapor and 99 to 94 volumes per cent of air. For petroleum hydrocarbon gases, the flammable range varies from 1.9 to 9.5 volumes per cent of vapors and 98.1 to 90.5 volumes per cent of air. When the vapor concentration is outside the range of flammability, flame propagation does not occur. The usual way to break up the flammable vapor-air mixture for gasoline and similar products is to reduce the air in the mixture below the amount required, that is, below 94 per cent for petroleum flammable liquids and below 90.5 per cent for petroleum gases. Carbon dioxide or dry chemical are recommended for this purpose. Dry chemical is also effective for other reasons (inhibits flame chain reactions, reduces heat).

Another way to make the flammable mixture nonflammable is to reduce the vapor content. In this connection the flash point of the oil is im-

portant. The flash point is the lowest temperature at which an oil will give off sufficient vapor to form a flammable mixture with air that will flash across the surface when ignition temperature is applied. Since an oil has to be heated to the flash point before it produces vapors that are essential for a flammable mixture, ordinary cooling methods will lower the temperature (except with gasoline and similar products) out of the range within which flame propagation is possible. This is illustrated in a kerosene fire. The flash point of kerosene is 126°F, and the temperature of the kerosene is assumed to be 80°F. When some of the oil at 80° is brought to the surface, the main body temperature is reduced below the flash point of the fuel. This reduces the vapor pressure and the vapor rate to the point at which the lower limit of flammability, 1 per cent, cannot be maintained; hence the fire is extinguished.

Generally, low-flash-point oils have high vapor pressures (Chap. 4). However, a crude oil with few light hydrocarbons may have a very low flash point and at the same time a low vapor pressure. Usually, high-flash-point crude oil has very low vapor pressure, or the pressure is insufficient to provide vapors above the liquid in an ignitable state. Invariably, an oil with an appreciable vapor pressure has a low flash point.

As a general rule, fires in oils that more readily vaporize and form flammable mixtures are more difficult to extinguish. On the other hand, fires in oils that require more heat to vaporize and form flammable mixtures are easier to extinguish since it is easier to alter the vapor-air mixture until it is nonflammable. Cooling is impractical for reducing vapor where the very low-flash-point oils, such as gasoline, are involved. The flash point of gasoline is —45°F, and therefore it can produce vapors within its flammable range at very low temperatures.

Class B fires can be classed as contained, uncontained, or a combination of both. In contained fires, the burning materials are in pits, pools, tanks, or tank trucks. In uncontained fires, the burning materials are not enclosed.

Contained Fires. High-flash-point substances include kerosene and other oils with flash points between 100 and 200°F and with low vapor pressure. Fire may occur in high-flash-point contained oil contaminated with low-flash-point oil. Many such fires can be put out by cooling in the same manner as before contamination. The time required for extinguishment will vary with the per cent contamination and the burning time.

Small high-flash-point fires are more easily and quickly extinguished by reducing the air content above the burning surface. The carbon dioxide and dry-chemical extinguishers are recommended. Small and large tank fires of both high- and low-flash-point oils can be extinguished by blanketing the surface of the oil with foam. Fires in pits, pools, or small tanks of

high-flash-point oils can be extinguished by using water spray to cool out the heated thin surface layer, which is providing the essential vapors. If the oil is viscous, a steam bubble froth will develop and assist in extinguishment. These fires can also be extinguished by digging a stream of water into the surface to stir up the oil in lower areas so that it will replace the oil at the heated surface. This method is effective if it reduces the main body temperature below the flash point. Vapor production decreases and the flammable mixture is broken up. Dry chemical is also effective on these fires.

Fires in storage tanks containing oil with a flash point above storage temperature can be extinguished by air agitation (Chap. 4). If high-flash-point crude oil is burning, however, air agitation will not succeed after the heat wave is well under way.

Low-flash-point products include gasoline, some jet fuels, and other products with flash points below 100°F and vapor pressures not more than 15 psi, as well as some crude oils. Small and large tank fires can be put out by blanketing the surface with foam. Reducing the air content (smothering by fog) below that required for burning is also effective. Carbon dioxide and dry-chemical extinguishers are suggested for smaller fires. Fires in very viscous low-flash-point oils can at times be extinguished by creating a froth on the surface by means of a spray or stream of water. For a fire in a large pit of gasoline, a foam blanket is recommended, applied preferably by a large foam-spray nozzle so that the foam will not knock the oil out of the pit or break up the foam blanket. Dry-chemical extinguishers are also effective for fires within their range. Tank-truck dome fires may be extinguished simply by closing the dome cover or with carbon dioxide or dry chemical.

Uncontained Fires. These are fires that involve flowing materials, and regardless of whether the oil has a high or low flash point, the flow of fuel to the fire should be stopped as early as possible. The protection of a fog stream and special protective clothing (Chap. 13) can enable firemen to approach the shutoff valve. If the valve cannot be shut off near a broken tank line, it may be possible to replace the gasoline flowing from the break by getting water into the tank; the contents will float on the water, which will then flow out of the broken line. The supply of water into the tank must be carefully watched and controlled so that the tank does not overflow. Then only the gasoline that has spilled out on the ground will have to be contended with. This action may abet closing or repairing the control valve.

Uncontained high-flash-point products, such as fuel oil, are difficult to ignite when flowing unless they are exposed to a considerable amount of heat. These fires do not travel back to the source over the unheated oil. Ground fires involving these products can be extinguished by the cooling effect of water in an ordinary stream, or as fog, or applied as foam.

Fire in uncontained low-flash-point products, such as gasoline, will travel quickly up to its source of fuel. The cooling action of water is ineffective. Streams of burning oil, even low-flash-point, can be covered with foam so that the oil flows under but the flames are stopped. Localized flames can in many cases be extinguished by dry chemical.

Combination Fires. An important rule is to extinguish the uncontained fire first. This means, in effect, first confining the fire by checking extension and then controlling and extinguishing it.

Liquid petroleum gas (LPG) is held in liquid form by its own vapor pressure, which is dependent upon the temperature. The chief constituents of LPG are butane and propane. LPG mixtures have Reid vapor pressure ranging from 15 psi to pressures in the low 20's. With such vapor pressures, it is obvious that cooling methods are not effective for extinguishment. The flammable range depends upon the mixture, but it will never exceed 1.9 to 9.5 volumes per cent of vapor and 98.1 to 90.5 volumes per cent of air. The flash points of these mixtures are too low to be of any real significance in describing their characteristics.

It is more important to know *when not* to put out an LPG fire than to know *how* to put it out. Many serious injuries have resulted from gas flashbacks where there would have been no hazard if the fire had been permitted to burn. The gas fire can usually be extinguished by dry chemical powder. Extinguishment is not advisable, however, unless the gas flow can be shut off immediately. These gases can travel much further than gasoline vapors before becoming sufficiently diffused that they are too lean to ignite. This is a severe hazard when these gases are released.

Where containers of LPG are exposed to heat, the internal pressure increases rapidly. Fog streams directed at the container, particularly around the exposed side, may retard this pressure buildup so that the contents will not be released through the safety plug or valve. Nothing can be taken for granted in such cases, however. Fire personnel should stay a reasonably safe distance away from the container, mindful that a jet of flame may issue from the safety plug or valve and mindful also of the direction it might take. An additional line should have been stretched and charged, ready for use in anticipation of any eventuality. Exposures created by the flame jet can then be quickly protected.

Open container and large spill fires in high-vapor-pressure products, such as the liquefied petroleum gases stored in spheroids, cannot be extinguished by any agent or method now available. Furthermore, it is questionable whether such fires should be extinguished, since extinguishment may create severe and possibly greater hazards at other and more widely scattered places due to reignition of the widely traveling flammable mixtures. In some situations, the fire service can only set up a defensive operation and take steps to shut off the flow of fuel to the fire.

Subway Fires. These fires seldom present problems of forcible entry or overhauling, but they can present many unusual problems, especially in rescue work and ventilation. Subway fires are notorious for their potential life hazard even when only minor. Rescue work is complicated by the large number of people affected, the possibility of panic, the presence of "live" third rails and moving trains, limited access for fire operations, limited egress for passengers, restricted ventilation and communications, and, at times, difficulty in locating the fire. In addition, poor visibility, heat, and smoke are obstacles.

Officers should consider the following checklist for rescue work in subways:

1. Request a power shutdown if necessary. Obviously, immediate compliance is not expected if it will intensify the life hazard. Transit authorities are in a position to check on trains near or within the affected area and should give them time to clear, particularly when the fire is in a tunnel under a river and emergency exits are far apart.

2. If the power is still on and if it is feasible, seek the cooperation of the transit authorities to run several trains together to form a long line of cars through which passengers may walk to the nearest station or emergency exit. If the power is off, passengers may be evacuated through the side doors to the bench walk and thence to the nearest station or emergency exit. Evacuation directly to the roadbed is also possible but less desirable due to the climbing involved and grease-soaked slippery cross ties.

3. When possible and practical, locate and extinguish the fire to reduce the heat and smoke. In any event, stretch and operate a line between the fire and endangered persons or between the fire and the means of escape as soon as possible. Fog might be used to drive the convection currents and smoke in a direction that assists rescue work.

4. Use whatever means are available to ventilate (fans, fog lines, smoke ejectors, etc.) and create a favorable draft.

5. Get sufficient manpower and equipment on the job. Since these fires are seldom more than one-line jobs, it is manpower rather than apparatus or equipment that is needed. However, masks, resuscitators, inhalators, and portable lights may be required. Get sufficient medical help.

6. Make certain that all endangered persons have been removed.

7. Establish effective communications as soon as possible to keep abreast of conditions, summon help promptly, and coordinate activities.

Decision making can be extremely difficult at subway fires, since the first step is to define the problem. This is made difficult because mechanical vents and moving trains may spread the smoke hazard over a wide area, a long time is required to check a large sprawled-out area, more

than one critical point may exist, there is an ever-present large potential life hazard and associated panic, and there is difficulty in communications and consequently pertinent information is delayed.

Activities can be assigned on a tentative, preplanned basis: field headquarters can be established so that incoming units can report and stand by until assigned on information received, and subordinate officers, preferably battalion or district chiefs, can be dispatched to obtain information. A limited part of the assignment on hand ordinarily accompanies each officer. Supervision of personnel is an all-important issue at these fires because of the electrical hazards, smoke, heat, poor visibility, and the possible jeopardy of fire personnel rescuing passengers under panic conditions. Where there is no life hazard, lines should not be stretched into "live" sections until it is definitely established that the current is off.

Ordinarily, the fire must be located first in order for rescue to be accomplished efficiently. However, at subway fires, it may be necessary to start rescue work before the fire is located because of both possible panic and the frequent difficulties in locating subway fires.

Ventilation can be achieved as previously described. Generally, there is a prevailing draft in subways, and it is easier to advance lines from the windward side. There should be a definite understanding between fire and transit personnel about the use of mechanical fans. In some cases, it is better to shut them down to prevent heat and smoke being drawn toward the rescue area.

Efficient communication is a must. Sound-powered phones that can be used without removing masks are ideal, and at least 400, and preferably 600, ft of wire on reels should be used.

Much thought must be given to placing and using hose lines. The line can be advanced more easily from the windward side, and almost invariably one line will suffice. If 1½-in. hose is used, the attendant high pressure may cause a burst. At times, a booster line stretched via an emergency exit not being used by passengers might suffice. Obviously, it will help to know where the fire is so that the most advantageous source of water supply can be selected and the amount of hose kept to a minimum. Where lines are long, it may be advisable to carry rolled-up lengths and call for additional manpower. Portable lighting equipment will help in making the stretch and reduce the hazard to personnel.

Although subway fires can usually be handled by a small stream, help frequently is needed because of the complexity and severity of the life hazard, the long hose stretches to put out the fire, and numerous other disadvantages. At least one deputy chief and two battalion or district chiefs should respond on the first alarm if possible. This permits the deputy chief to set up field headquarters and dispatch subordinate chiefs to obtain information.

When help is needed, units with good manpower, such as rescue and squad companies, and with special equipment such as pnealators, resuscitators, or inhalators are preferable to ordinary engine and ladder units, although difference in responding time may preclude any choice. Pnealators and resuscitators are especially advantageous because they operate automatically until the overcome person starts to breathe on his own again; inhalators, which must be supplemented by artificial respiration, increase the need for manpower. Departments that have special mask-service units and field communication units can use them to advantage at subway fires. In many cases, the cooperation of the police department and hospitals is of great importance.

Arson. Arson is an ancient crime, involving the willful and illegal setting of fire to structures and property, accompanied in some cases by loss of life. Hence, its detection is an integral part of firefighting. The number of fires that are of incendiary origin is a small proportion of the total, but it is possible that a much larger proportion of the total "loss" than is generally supposed is incendiary.

Motives. The first and foremost motive is profit. Approximately three-quarters of arson cases are motivated by the desire to collect fire insurance. A desire to collect life insurance may also be the motive.

The profit motive sometimes leads to eliminating competitors by burning out a business; some fires have been set by a man wanting a job to impress upon owners of property the need for a watchman.

Revenge is also a major motive. In some parts of the United States it is traditional to avenge family insults or harmful testimony given in court by burning out the offending party (his home, barn, or other property).

Many fires have been set because of jealousy. They are almost invariably associated with romantic triangles. In several cases, young men afflicted with a "hero complex" set fires and later participated energetically in rescue work.

Covering up a crime is a strong motive for arson. Occasionally a murderer will burn a building to destroy evidence and the identity of the victim. Robberies are often followed by fires planned to prevent the discovery of the robbery; most fires of this type are set to cover shortages or embezzlements. It is a matter of record that several county courthouses have been burned down in the United States to cover up shortages by county treasurers or tax collectors. In some chain stores, the manager has committed arson to cover a shortage of stock that he sold himself or otherwise illegally disposed of. If official records, financial or other, are involved in the fire, arson is more readily suspected.

In wartime, sabotage is a motive. Fire is perhaps the saboteur's greatest weapon. The number and severity of sabotage fires are difficult to estimate, since it may not be public knowledge that fires have occurred.

Pyromania, a mental illness, is really a subject for psychiatric discussion. Many explanations have been offered for this affliction, but for the fire service it suffices to know that pyromaniacs have urges, often uncontrollable and inexplicable, to set fires. It has been estimated that about 15 per cent of known arson fires are set by pyromaniacs. There are reasons to believe that youngsters of sixteen and seventeen may be affected temporarily by pyromania, setting fires for only four or five years as a rule; those who start to set fires after age forty, however, tend to keep on setting them quite persistently. The latter group are more dangerous, and the sooner they are apprehended, the better. Fire-service personnel should be on the lookout, particularly at suspicious fires, for persons who appear unduly interested or who are present at an inordinate number of fires. It is helpful to know that the alcoholic pyromaniac is a prime suspect and that intelligent pyromaniacs are rare.

Pyromaniacs always work alone. They are often feebleminded, epileptic, or subnormal. In some cases, pyromania has been traced to head injuries suffered in youth.

Some consider the alcoholic group as the most dangerous. It is not necessary that they be intoxicated; a comparatively small amount of alcohol may stimulate them sufficiently. Alcoholic pyromaniacs have their peculiarities also: they generally work at night, they have a weakness for setting fires in hallways, dumbwaiters, cellars, vacant apartments, barns, lumberyards, and other isolated structures, and they very rarely use oil.

Suspicious Circumstances

1. A fire of abnormal extent when the fire department arrives. This is more striking if the fire occurs during the day and on a weekday.

2. The color of the smoke may indicate that the burning material is foreign to the occupancy; for example, white smoke may mean the presence of phosphorus, yellow smoke may mean gunpowder, and black smoke may mean petroleum and naphthalene.

3. Unusual-colored flames. Red flames may be caused by petroleum, blue flames by a small amount of alcohol, and orange flames by a large amount of alcohol.

4. Unusual odors. The characteristic odors of gasoline, kerosene, illuminating gas, and alcohols are readily discernible. Unusual odors of camphor or cabbage may reveal the presence of nitrocellulose or carbon disulfide, respectively.

5. A fire of unusual intensity. This may be due to the use of combustion accelerators.

6. A fire that takes a peculiar path; for example, if it originates near a vertical shaft that would ordinarily draw it upward but has nevertheless spread 100 ft on the original fire floor for no ordinary reason.

7. The presence of several fires definitely separated from each other.

8. Doors and windows found unlocked. This is particularly suspicious at night fires in business occupancies.

9. A fire in an inexplicable location, for example, clothes closets or open drawers.

10. Evidence of trailers, open gas jets, or similarly significant conditions. A trailer is an incendiary device designed to carry fire in a desired direction. It may be in the form of a combustible substance, such as loosely braided sisal, at one end of which a lighted candle is placed. When the candle burns down, it ignites the sisal, along which the fire travels rapidly. In some cases the combustible material is saturated with a flammable liquid to accelerate the spread of the fire.

If suspicion of arson is aroused, attention should be given to the following items:

1. Unusual disarrangement of structural contents: bureau drawers open and contents upset, pictures removed from walls, clothes closets practically empty, and household pets removed.

2. The dress and demeanor of occupants. Occupants fully dressed at night fires might rightfully be suspected.

3. Drawn curtains, possibly intended to delay discovery of the fire, or obstructions placed to impede fire operations.

4. Residues caused by the fire, which may furnish additional proof that the fire is incendiary in nature. Sulfur candles, nitrocellulose, and phosphorus leave a black residue, fibrous residue, and brownish red bubbles, respectively.

5. The burning of flooring and charring between the tongue and groove; possibly inflammable oil or some other substance was pocketed at that point.

6. The presence of unconsumed objects near the point of origin of the fire. Evidence of trailers may be found.

7. The presence of unduly interested persons or of people who are seen suspiciously often at other fires. These are usually "firebugs"—occupants are seldom in this category.

8. Fire personnel should be sufficiently versed in the laws of arson to be effective in detecting and prosecuting it. They should understand the common causes of fire and the methods commonly used in setting fires or causing explosions. This entails some knowledge of chemicals that can cause spontaneous ignition or that have explosive qualities. They should also know the ordinary hazards that exist in various types of buildings and occupancies. This helps determine whether the fire was due to an existing cause or to incendiarism.

Fires of suspicious origin are those which occur under definitely suspicious circumstances but for which the cause is not fully ascertained

and no physical evidence of the crime is detected. Incendiary fires are those which are set and where definite physical evidence of the crime is found.

Physical evidence that arson has been committed must be produced. Whether such evidence is already available or only suspected, the fire marshall should be notified as soon as possible. His special training ensures the unearthing of evidence if it has not yet been found. Pending the arrival of the fire marshall, care must be taken to safeguard whatever evidence is available. When possible, pictures should be taken of evidence, particularly if it is of a transitory nature. Responsibility for the fire must be directly connected with an individual. A confession is acceptable evidence if it is suitably corroborated, but other evidence may establish guilt.

Conclusions. The prevention of arson is an integral part of fire-prevention work. It is essential to detect and prosecute arsonists vigorously, but it would obviously be a greater accomplishment if arson were prevented or reduced. Psychiatrists may eventually be able to help pyromaniacs. Educators should instruct students beginning in the lowest grades so that they will have a better attitude toward fire prevention. When fire-prevention training has been properly integrated into the educational system, desired results can logically be anticipated. A long-range program of this kind is best administered by those who seek to achieve societal rather than political benefits.

PART 4

Leadership

15

Management Techniques

Leadership in management is the ability of an individual to exert interpersonal influence through the medium of communication toward the achievement of a goal, or the ability to motivate people to think and direct their efforts. It will be considered from this viewpoint in Chap. 16. In another sense, leadership implies creative thought and action, the opening up of new channels and venturing into virgin territory. This book as a whole and Part 4 in particular are intended to exemplify these implications in relation to firefighting.

Firefighting activities always have been, and undoubtedly will continue to be, important cooperative activities. Management principles can have an important effect on cooperation and coordination in these activities. Scientific knowledge or technical ability at firefighting are useless unless those at all managerial levels—officers of all ranks—can effectively coordinate the human resources under their command. A group leader can get things done only by coordinating the efforts of the group members. In this chapter are considered the nature of management and the several managerial functions.

The Nature of Management

Management is the art of getting things done by other people. It is utilized by officers of all ranks, and it is important that both officers and subordinates understand the nature of management. If a superior understands properly, he will not lose time by working at nonmanagerial ac-

tivities that should be done by subordinates. If a subordinate understands management, he will not think that managers "do nothing"; on the contrary, he will probably appreciate an officer who discharges the managerial functions efficiently. Too many officers, especially at lower levels, engage unnecessarily in nonmanagerial activities. Managers may, at their discretion, engage in nonmanagerial activities, but subordinates never undertake executive functions.

Managers perform the same functions regardless of the type of organization structure or their place in it. As managers, all are concerned with getting things done by others, and at one time or another they carry out all the duties characteristic of managers. Because of the universality of managerial functions, anything significant said about one manager applies to all managers. As a result, it is possible to develop a theory of management applicable to all executives in all occupations. In addition, managerial knowledge and experience are transferable from unit to unit and from enterprise to enterprise. To the extent that tasks are managerial rather than technical, executives, with the proper motivation, can employ their skills as well in one occupation as another. The fire service can benefit from the theory of management, which applies to officers, acting as managers, at all levels.

Managers need not possess nonmanagerial technical skills, such as those possessed by lawyers, doctors, and accountants, which are acquired through study and practice. Managers must be able to use skillfully the talents of the technically trained persons under their direction. However, there are two things a manager must know about technical skills: he should know which skills are employed in his particular occupation and be familiar enough with them to be able to ask discerning technical questions (for example, the head of a fire department, reading about research on a certain firefighting technique, should be able to consult intelligently with his advisors on the merits of the new technique); he must understand both the separate role of each skill and the interrelationship between skills. At a major fire operation, roles are played by engine, ladder, and rescue companies, by mask-service, communications, and supervising engineer units, etc.; the officer in command must know how best to assign them to utilize the capabilities most fully.

In the fire service, particularly at the higher levels, officers may have technical as well as managerial skill. Technical competence often gives a person a position of prominence and respect in a group, which augments his leadership capabilities and his effectiveness in operating at fires.

Authority and Responsibility. Authority is the key to good management. It confers the right of superiors to require conformity of subordinates to decisions, and it gives managers the power to issue orders, which

are the specific means by which activity is initiated and modified. In addition, it is the basis of responsibility and the force that binds an organization together. Authority can be defined as legal or rightful power either to command or to act. It is power over others. A person who has authority has the power to command others to undertake or not undertake activities appropriate to the realization of a given purpose. Since management theory is necessarily based on superior-subordinate relationships, it is founded on the concept of authority. A superior must have sufficient authority to obtain compliance with instructions, whether through persuasion, coercion, economic or social sanctions, or other means. A manager has *authority delegated* to him, *responsibility exacted* from him, and *duties assigned* to him.

The Source of Authority. There are two theories about the source of authority: the formal theory and the acceptance theory. The formal theory states that authority is power transmitted to an individual from a social institution. Institution is used in the sociological sense, meaning a complex of laws, a code, mores, or folkways by which a social group attains and enforces its purposes. Institutions can be political, economic, religious, educational, or social. Private property, for example, is a social institution, deriving its characteristics from group behavior.

The acceptance theory of authority states that a manager has no real authority unless and until individual subordinates confer it upon him. Individuals always have an opportunity to influence decisions of superiors by accepting or rejecting them. In effect, the sphere of authority is defined by the degree of acceptance of the subordinates. This type of authority is obviously impractical for the fire service.

Formal authority without leadership tends to be an abstraction. It is important for officers in the fire service, particularly those newly promoted at the lower levels, to realize that rank and authority by themselves are not enough. To be effective, an officer needs several important qualities, notably leadership, or the ability to encourage subordinates voluntarily to carry out assigned tasks efficiently and with good will (Chap. 16). When subordinates have a sense of voluntary dedication to the performance of their tasks, morale is high. Successful leadership can achieve this result.

Limits of Authority. There are two categories of limits on authority: external and internal. External limits are those imposed by physical limitations of men and equipment and by the existence of conflicting or coexisting authority. For example, ownership of private property confers authority that may be circumscribed by the authority of the fire service to conduct operations. There is no point in an officer ordering firemen to walk up a wall or raise a 75-ft aerial to an 85-ft roof; these operations are not physically possible. The exercise of authority is limited by social

and economic considerations and by the need for internal consistency: an officer cannot order men to take risks that unnecessarily jeopardize them, he cannot provide himself with equipment except as specified by a budget, and he must exercise his authority to conform with departmental regulations and policies.

Internal limits on authority result because, in practice, an order is only as effective as the willingness of subordinates to obey it. Subordinates of today, for example, are more apt to rebel against autocratically exercised authority and more apt to submit to democratically exercised authority than subordinates of twenty or fifty years ago.

Effective orders must be issued to persons definitely understood to be subordinates (an officer cannot issue an effective order to another officer of the same rank); they must concern matters pertinent to the activities in hand; and they must be enforceable [there must be sanctions that can be employed against subordinates who refuse to carry out orders or who carry them out inappropriately (Chap. 17)].

Departmental regulations impose limitations by specifying the authority of officers of different ranks, by requiring officers to avoid unnecessary jeopardy of personnel at fires and excessive and unwarranted damage during forcible entry and overhauling and to use discretion in applying water at fires, etc. Instructions likewise make officers aware that their authority in utilizing the right-of-way prerogative of fire apparatus is limited, as is their authority to block streets during fire operations in the sense that street conditions should be restored to normal as soon as practicable.

Responsibility. Responsibility may be defined as the obligation of a subordinate to perform the duties assigned by superiors. The essence of responsibility is obligation. Authority and responsibility are intimately connected in the chain of command, where officers have authority over their own subordinates but are also responsible for the discharge of duties assigned to them by the commanding officer, who has authority for the fire operation as a whole. In such a case, an officer is both a superior and a subordinate. Authority flows from higher to lower ranks, that is, from battalion or district chief to captain, from captain to lieutenant, etc. At fire operations, where a company may be under the command of a lieutenant, authority may flow from the chief to the lieutenant when an assignment of duties is made. In some large departments, the captain responds with his unit only about 25 per cent of the time, since the work week is about one-fourth as long as the fire-service week. When the captain is off duty, the unit will be in the charge of a lieutenant. The subordinate to whom authority is legitimately delegated naturally assumes the associated responsibility, which is the obligation to carry out the assigned duties.

Every subordinate should know who his superior is and to whom policy matters beyond his authority must be referred. This development is best achieved by a clear understanding and application of the scalar principle, which establishes a chain of direct authority relationships from superior to subordinate throughout the organization. Fundamentally, this principle states that authority for engaging in any undertaking must rest somewhere and that there must be a clear line from that source to every rank in the organization.

Delegation of Authority. Authority, but not responsibility, can be delegated. A chief officer may give an assignment to a captain or lieutenant. When the subordinate officer accepts the assignment, he creates responsibility for himself to his superior officer. However, no superior delegates any of his responsibility. A chief officer may delegate authority to carry out certain duties at a fire, but he remains responsible for the overall conduct of the operations. The head of a department cannot avoid total responsibility for the conduct of the entire department. If a deputy chief, responding to a fire, conducts operations on the basis of information given to him by subordinates, which is subsequently shown to be incorrect and to have had disastrous results, the chief cannot avoid the responsibility or shift it to the officer who gave him the faulty information.

Just as authority is the key to management, delegation of authority is the key to organization. It may be defined as vesting in a subordinate a portion of his superior's authority, and its primary purpose is clearly to bring about an organization that is effective and efficient in achieving group objectives with the least cost in time, materials, and dissatisfactions. Without delegation of authority, organization would be impossible. The grouping of activities and their assignment necessarily involve delegation of authority to ensure that duties are effectively discharged.

Delegation is necessary because there is a limit to the number of subordinates a superior can effectively manage; this number varies with the training possessed by subordinates, the clarity of plans and policies, the degree to which objective standards can be applied, the effectiveness of communications, etc. Obviously, no superior can delegate authority that he does not have. Obviously, also, he cannot delegate all his authority without, in effect, passing on his position to the subordinate.

Delegations of authority may be general or specific and written or unwritten. In any case, they must be accompanied by some kind of assignment of duties. Written and specific delegations have advantages because conflicting or overlapping assignments will be more apparent, the assignment will be better understood, and there will be less uncertainty. Nonspecific delegations of authority may result in confusion, with subordinates forced to operate more slowly, feeling their way and defining their authority by trial and error. This usually places them at a

disadvantage. A manager would do well to balance the costs of uncertainty against the effort involved in making authority delegation specific.

Very often at fires, orders are oral and nonspecific, such as "check that exposed building," "get that roof opened up," or "get the people out of the building." Because of the time element and other factors, it is not opportune to be specific here. Fire personnel have been trained to know what is meant by such orders. Hence, these nonspecific oral orders imply delegation of authority as broad as is necessary to get the job done. For example, an officer given an order to "check that exposed building" knows that he has the authority to force entry to the building, ventilate at the roof and unexposed sides, close windows that are intensifying the exposure hazard, use extinguishers and the standpipe system within the building as conditions warrant, move exposed stock, shut down sprinklers operating unnecessarily, etc.

Sometimes when new top-level jobs are created, authority delegations cannot be very specific at the outset. One of the first duties of the new appointee is to describe the job and to clear the description with his superior and, ideally, with managers on the same level, whose cooperation is important for successful operation. Otherwise, the cost of vague authority relationships may have to be paid in organizational friction, time lost through unnecessary meetings and negotiations, jealousies, and stepped-on toes.

Very specific delegations of authority may result in inflexibility, and a manager may regard his job as a staked claim with a high fence around it. This can be eliminated by the proper example of leaders and by making necessary changes in organizational structure an accepted and expected thing. The intentional development of a tradition of change will do much to offset undesirable rigidity of attitude.

Shared authority is demonstrated where responsible managers or officers deliberately insist that power in given situations be shared by subordinates. Such managers obviously want an acceptable group decision, but in a sense they have not delegated authority at all, since the top superior retains authority to make a final decision if he so chooses. Shared authority is seen in a fire house when the captain consults his lieutenants about house rules, committee work schedules, arrangement of lockers and furniture in office, etc.

Splintered authority exists wherever a problem cannot be solved or a decision made without pooling the authority of two or more officers, for example, in fire houses with two or more captains. In making decisions about house rules, and other matters, the captains concerned must pool their authority and agree. Splintered authority cannot be avoided, especially for unusual problems. However, it sometimes indicates that au-

thority has not been properly delegated and some reorganization is required.

All delegations of authority are subject to recovery by the delegant. It is characteristic of authority that the original possessor does not permanently dispossess himself of this power by delegating it. This is logical, since the original possessor of authority cannot dispossess himself of his original responsibility. If a superior makes mistakes in delegating authority and, as a result, assignments are not carried out effectively, he may exercise his right to recover authority. Delegated authority is frequently recovered when departmental objectives, policies, and programs, organizational structure, and assignment of personnel are modified.

Authority is said to be *centralized* wherever superiors tend *not* to delegate authority to their subordinates. This practice not only limits the number of subordinate officers in an organization but severely limits its efficient size, since departmentation (the grouping of activities and subordinates into departments) requires delegation of authority. In contrast, superiors who employ the process of departmentation tend to delegate much authority to their subordinates. In such cases, authority is said to be *decentralized*. Extensive delegation of authority makes possible the expansion of an organization.

There must be parity of authority and responsibility. It is obviously unfair to hold an officer responsible for duties that he does not have the requisite authority to perform. On the other hand, where authority has been delegated, the officer should be held responsible for its use.

Managerial Functions

The most important managerial functions are planning, organization, staffing, direction, control, and coordination. The principles of management were primarily developed for business and military organizations, but many can, with appropriate variations, be applied to fire departments. These functions provide a framework within which the principles of management can be classified and by means of which such factors as leadership, morale, and discipline (Chap. 16) can be better understood in relation to management.

Planning. Planning is the function of selecting objectives and determining the policies, procedures, and programs necessary for their achievement (Chap. 18). It is the intellectual process of determining conscious courses of action and basing decisions on purpose, facts, and considered estimates. Planning is decision making, since it involves choosing among alternatives; one might say it is the rational process of making decisions on any phase of an operation or activity.

Managers at all levels engage in planning. They must be able to visualize the enterprise or operation as they wish it to become because planning decisions uniquely affect future developments.

Policies are general statements or understandings that guide the decision making of subordinates. They are often implied from the actions of officers, and although they are seldom specific, they must be consistent and integrated to contribute to the realization of objectives. They are normally made at all levels. For example, lieutenants may formulate policies relative to maintenance of quarters, drills, and activities connected with fire-prevention and fire-extinguishing work; captains formulate policies relative to training of chauffeurs, location and distribution of lockers, dormitory regulations, house rules, committee work, and housewatch duty.

In addition to planning by determining policies, company officers make decisions on the scene of fire operations, a more immediate kind of planning. They decide what men should carry certain tools, what route should be taken in responding to an alarm, what hydrant should be used, what type of hose and nozzle should be selected, whether to initiate an interior or exterior operation, how the line should be stretched (stairway, fire escape, or ladder), where the second line should be stretched, etc.

Procedures involve selection of a course of action to be applied to future activities; they are guides to action and detail the exact manner in which activities are to be carried out. They take the form of a chronological sequence. Procedures for personnel administration are more numerous and exacting largely because of the necessity for more careful control and a reduced need for discretion in action.

Programs are a complex of policies and procedures associated with an action plan. Frequently, basic programs require the development of derivative programs: the basic fire-prevention program may require subordinate programs for training fire personnel and educating the public.

Budgets are essentially plans, statements of expected results expressed in numerical terms. They may be expressed in financial terms or in man-hours, machine-hours, or any other measurement that can be reduced to numerical expression. A budget for building inspection could be a statement of results anticipated in terms of the number of violations, types of violations, man-hours involved, etc.

The establishing of rules is also part of the planning function. Rules are frequently confused with procedures, although the two are entirely distinct. A rule requires that a specific and definite action be taken in a given situation. It is like a procedure in that it guides action, but it differs in that no time sequence is specified. A rule may be a part of a pro-

cedure, but in such cases it usually refers to a specified action apart from the chronological features of a procedure. For example, the procedure covering actions to be taken in connection with reports on the way to department headquarters through official channels may incorporate the rule that such reports are to be listed by intermediate officers.

Rules should be distinguished from policies. Policies are to guide decision making by marking off areas of discretion, and rules are to guide action where departmental welfare requires no deviation from a stated course of conduct.

Organization. Organization involves determining and enumerating the activities required to achieve a desired objective. For example, the commanding officer may organize fire operations by deciding to initiate an interior attack to extinguish a fire within an unoccupied structure and deciding that the activities required to achieve extinguishment are forcible entry, ventilation, overhauling, and the use of hose lines.

Grouping of activities is essential to organization. They are grouped along functional lines to facilitate assignment. Accordingly, all activities of forcible entry, ventilating, and overhauling are grouped together and usually done by ladder companies; activities associated with the placement and use of hose lines (such as selecting hydrants or source of water supply, type, amount, and size of hose, type and size of nozzle, and pressures used, stretching, placing, and using hose lines, and replacing burst lengths and taking up hose lines) are grouped together and generally done by engine companies. Assignments are made in accord with the functions of the units available, and they are expedited and simplified by grouping.

At fire operations, authority commensurate with the responsibility involved is automatically delegated. The several responsibilities are coordinated by effective supervision (see below, Coordination).

This concept of organization also functions when smaller units discharge their duties at fire operations: the officer who receives an assignment groups the activities for which he is responsible, assigns some of them to subordinates, delegating to them the requisite authority, and provides supervision to the efforts of all group members.

The organization structure is a tool for accomplishing objectives, therefore it must fit the task and reflect the compromises and limitations imposed on the officer in command. Efficient organization contributes greatly to the success of the unit, and for this reason the application of organization principles is very important. Careful attention to these principles will produce a structure in which the authority and functions of all units are clearly defined.

Staffing. Staffing is comprised of activities that are essential in manning the positions provided for by the organization structure. It includes hav-

ing on hand an inventory so that managerial openings can be foreseen and readily filled (in some fire departments this need is covered by official quotas, which indicate the number of officers required for each rank, and by eligible lists, which indicate available candidates for the openings), defining job qualifications, appraising and selecting candidates for jobs, and training candidates and incumbents.

The view that staffing is a significant managerial function is comparatively recent, and it is receiving greater acceptance because many persons now feel that the most important element in an organization is the people in it. Hence the recruiting, training, appraising, and promoting of personnel have achieved greater stature. In some fire departments, promotion is made exclusively according to standings on civil-service lists, over which fire-service administrators have no jurisdiction. This practice is not in accord with the principle that authority should be coextensive with responsibility, and in some ways it handicaps administrators in carrying out the function of staffing.

Direction. Direction consists of activities related to guiding and supervising subordinates (Chap. 16). An officer who wants to give successful direction must (1) inculcate in his subordinates a keen appreciation of the traditions, history, policies, and procedures of the fire service, (2) know the organization structure, become familiar with his duties, and know how to use his authority effectively, (3) develop the ability to work with and learn from others, both superiors and subordinates, (4) be familiar with alternative means and have the intuition to employ the right one at the right time and in the right way in the direction of subordinates, and (5) above all be an effective leader.

Control. This function includes activities designed to compel events to conform to plans. It is the measurement of the activities of subordinates and their correction so that plans will be carried out as desired. This concept of control implies that planning must precede control and that plans are not self-achieving. It means that the superior must trace poor performance to its source and see that it is remedied. If equipment is not cleaned and dried after use, for example, the subordinate officer responsible can be instructed to make it his business to supervise and inspect the cleanup personally in the future. He, in turn, will probably find it best to assign specific jobs to each man in order to eliminate a "let-George-do-it" attitude and simplify checking on performance. If the trouble continues, other corrective steps can be taken. Disciplinary action, ranging from the withdrawal of minor privileges to the pressing of formal charges, can be taken against individuals responsible. These measures should never be taken lightly or without careful consideration, but responsibility must always be personal and each individual or group must answer for what it either does or fails to do.

Many routine activities, such as conducting roll calls, drills, and tests

for masks, are amenable to control through established standards. Standards permit appraisal of performance and detection of deviations. Appraisal of performance can be made by personal observation or by a study of motion-picture films of fire operations. Correction can follow, if necessary, by means of supervision, training, or disciplinary action. The control process always involves three steps: (1) the establishment of standards, (2) the appraisal of performance, and (3) the correction of deviations.

Coordination. Coordination is the essence of management. Administration has been defined as the coordination of activities essential to the achievement of the enterprise objective and of the personnel associated with these activities. Obviously, therefore, a successful administrator is a successful coordinator.

The need for coordination arises out of differences of opinion as to how group goals can be reached or how conflicts between individual motives and group objectives can be harmonized. Even where motives and objectives tend to be the same, as in religious or fraternal organizations, there may be differences of opinion as to how to accomplish goals. The manager has the problem of reconciling differences in approach, effort, or interest and harmonizing individual goals and actions so that they will best achieve group objectives.

The best coordination in an organization occurs when individuals see how their jobs and goals harmonize with the dominant goals of the enterprise. This desirable condition is realized when enterprise objectives are known and understood at all levels in the organization. If managers are uncertain about enterprise objectives, splintered efforts result and coordination is adversely affected. Certainly all fire personnel should know that the functions of the fire service are to prevent fires and, when necessary, to protect life and property against fire. This book deals primarily with firefighting, but it must be clearly understood that the fire that has been prevented has been best handled. In the functions of the fire service, prevention and extinguishment supplement each other. For example, during inspections intended to minimize hazards, and thereby prevent fires, conditions of import during fire operations should be noted for possible use; likewise, during fire operations, conditions calling for preventive action should be noted, reported, and followed up.

Coordination of fire service activities is obviously essential so that each unit may contribute its maximum effort. To achieve the desired coordination, the officer in command should apply the principles of coordination. An effective communication system is essential.

The first principle of coordination is that of *direct contact:* it states that coordination is achieved through interpersonal relationships of people in an enterprise. People exchange ideas, ideals, prejudices, and purposes through direct personal communication much more efficiently than

by any other method, and they find ways and means to achieve both common and personal goals. The participating parties recognize an identity of ultimate interests. There are many subjects for debate in the fire service, such as the priority of firefighting over fire prevention, fog versus solid streams, and metal versus wooden aerials, but everyone in the fire service recognizes the identity of their ultimate interest, which is the prevention of fires and the protection of life and property.

The second principle is that of *early coordination* in the first stages of planning and policy making since it is easier to unify plans before they are put into operation. Policies and procedures relative to fire lines and securing property should be agreed upon by the fire and police departments; departments of water, gas, and electricity and the fire department should coordinate in advance policies relative to hydrants, mains, and water pressures; many departments, including the fire department, coordinate policies so that they can effectively participate in preplanned operations for disasters and major emergencies. When a chief officer contemplates sending a greater alarm, in order to get maximum results from the responding units, he should consider the need for coordination and, before the greater-alarm units arrive, he should decide upon definite objectives for responding units, get the cooperation of the police in improving pertinent street conditions, see that favorable hydrants are available and unobstructed, select vantage points for operating streams, get the cooperation of the water department to maintain sufficient pressure, and notify the responding units by radio how to approach the area, where to report, and what type of operation to anticipate.

The third principle of coordination states that *all factors in a situation are reciprocally related;* this is to say that when A works with B, each finds himself affected by the other and both are influenced by all persons in the total situation. This is so because, among other reasons, individuals, however similar their training (and objectives and motives), strive to achieve their goals through different approaches, interest, and effort. The work of Lieutenant A in a ladder company will affect the work of Lieutenant B in the engine company: premature ventilation can magnify the engine company's problems, and inadequate or delayed ventilation can make it difficult for an engine company to advance a line; the lieutenant of the engine company will affect the work of the ladder company by the care he exhibits in placing his apparatus at a hydrant. Lack of consideration here may prevent the ladder unit from placing its apparatus properly and increase its problems.

Some chief officers have characteristic policies at fire operations: some advocate the use of fog more than others; some want the second line stretched via the fire escape; others want the second line to back up the first line. The policies of chief officers affect the work of subordinate

officers, and, in turn, the chief officer is influenced by the efficiency or inefficiency of his subordinates.

Achievement of coordination is largely horizontal rather than vertical. People cooperate as a result of understanding one another's tasks. Good coordination removes critical problems as they arise; excellent coordination anticipates and prevents their occurrence.

The supervisor is the most ancient as well as the most important device for achieving coordination. His chief duty to his superior is to see that his subordinates are achieving a high grade of coordination among themselves and in their relationships with other groups. Supervisors do not directly coordinate the work of subordinates but rather employ directional devices (orders, written or oral), teach principles of coordination, illustrate their application, and determine the quality of synchronized effort.

Organization is also an important device for achieving coordination, since the span of management limits the number of subordinates that a supervisor can properly direct. Enterprises such as a fire department are generally of such a size that they require the services of many officers. Careful attention to the principles of organization will produce a structure in which the authority and functions of all units are clearly defined and whose framework facilitates the interaction that is essential to correlating activities.

Other devices for achieving coordination are written communications, such as procedures, bulletins, letters, circulars, and department orders, as well as mechanical devices for the transmission of ideas. Personal contact is the most effective means of communication. Group meetings are effective devices, and this technique can be used by officers at drills and conferences. This technique recognizes the fact that coordination cannot be imposed from the top but must be achieved horizontally. Liaison men or coordinators can be used to coordinate efforts of fire departments and civil defense organizations or between different fire departments in mutual-aid programs.

The officer is responsible for the quality of synchronized effort among his subordinates. He utilizes the managerial functions to improve this quality. Even though he cannot order coordination into existence, he is responsible for seeing that it occurs. He achieves this in two ways: he creates a conducive atmosphere and environment by creating an appropriate organization structure, by selecting subordinates with care and training and supervising them effectively, and by explaining the integrated plans, policies and programs and establishing appropriate controls to ensure that they are carried out; finally, he makes certain that his subordinates understand and act on the principles of coordination.

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Direction and Command

For effective direction, there must be unity of command. Each subordinate should report to only one superior, and chief officers should usually avoid giving orders directly to members of a unit; orders should be transmitted through the unit or company officer. It is possible for a subordinate to be delegated authority by two or more superiors and it is logically possible for him to be held responsible by them, but the difficulties in such a situation are obvious. The delegation of power by more than one person is likely to result in conflicts in both authority and responsibility as well as in harmful inefficiency.

Direction is the executive function of guiding and overseeing subordinates. The difference between direction and other managerial functions is comparable to the difference between sitting in a car with the motor idling and putting the car in gear. Direction is intimately concerned with getting things done. Subordinates receive direction; they never give it. Officers at intermediate levels give supervision—but only to their subordinates.

In the fire service as in other organizations, subordinates must be directed because it is through them that work assignments are carried out. Direction can be considered, therefore, as fundamentally a matter of managing human behavior. Consequently, superiors must mold the activities of their subordinates in such a way that they coordinate effectively the work of the unit, cooperate sincerely with others in the organization, and live up to socially approved standards of conduct both on and off the job. To give successful direction, the superior must have

adequate authority, must motivate his subordinates to promote the accomplishment of unit and organization assignments, must ensure harmony of objectives, must maintain effective discipline, must be a skillful leader, and must maintain high morale.

The approaches to direction are extremely diverse. There are not only good and bad practices but several degrees of each. Superiors must understand these practices and select the most effective as well as the most appropriate. He must personalize his contacts with subordinates.

Direction and Delegation of Authority. Authority is a prerequisite of an officer inasmuch as it is the right to command a subordinate to undertake or refrain from undertaking an activity. When an activity is assigned to an officer, commensurate authority must be delegated. Assignment of duties and delegation of authority defines the job of officers. Difficulties arise when superiors must decide upon specific versus general assignments and delegations of authority. At first glance, it might appear that to assign duties, one has only to specify which officer is in charge of what activity. On a closer look, however, questions frequently arise of what is involved in a given assignment, even when it appears clear and exact. For example, what is meant by the assignment to "advise your superior about such and such a procedure"? Does it mean constructive suggestions, presented in tentative written form? If so, when is such a report required? Is the report to follow a specific form and contain specific information? Again, what would one do with an assignment "to study the equipment market constantly?"

A common difficulty associated with assignment of duties in general terms is overlapping of work assignments. Delegation of authority is even less exact than the assignment of duties. It often states merely that the subordinate has the authority to carry out the assigned duties, but since the scope of the assignment may not be clear, the delegatee is certain to have difficulty in interpreting his authority to carry it out. The type of authority granted involves the question: how specific can a grant be? The answer depends upon the extent to which the work assignment can be specific. Particularly at fire operations, assignments frequently are made in general terms. It is possible to generalize that specific authority can be granted if the work assignment is specific and that the delegation of authority is broad at the top of an organization and becomes increasingly narrow as lower echelons are reached.

Implied authority is of particular interest to fire officers because assignments are so frequently given in general terms and also because conditions are often met for which no prescribed procedures have been established. In carrying out a general assignment, such as "open up the roof," officers have the implied authority to select specific equipment to be taken to the roof, to select means of reaching the roof (aerial ladder,

adjoining building, fire escapes), to select means of opening up the roof (opening stairway bulkhead or shafts terminating at the roof, chopping openings at appropriate spots, opening skylights), to assign men to various tasks, and to provide means of escape via roof rope and life belts. Obviously, fire officers have implied authority to abandon positions to which they were assigned when it becomes apparent that their unit is in unnecessary jeopardy. Confronted by situations for which no standard procedures have been established, officers have implied authority to operate in a manner most likely to achieve the objectives of the fire service, namely, to prevent fire and protect life and property.

Superiors with a negative attitude toward the delegation of authority dislike to make any delegation at all and usually feel that delegations can be made exactly and accurately and that the results they personally anticipate will be achieved. Disappointments in this respect are likely to lead to harsh judgments on the ability of the subordinate to whom they may have been forced to delegate authority. These superiors feel untoward frustration when their plans fail to work out where everything seems neat and clear to them. They often feel that only they are capable of doing the job, and they lack trust in subordinates, whose errors, they fear, will jeopardize the welfare of the unit. These men may feel insecure in their position and fear that errors of subordinates will adversely affect them as superiors. The effects of a negative attitude toward delegation have serious results, primarily because officers with such an attitude are incapable of developing successors. Men prefer not to work for such a superior. The negative attitude toward delegation limits the size of an organization and retards its growth. A superior with such an attitude is antagonistic to departmentation and the concomitant delegation of appropriate authority.

Superiors with the positive attitude toward delegation of authority do not feel their personal security threatened by it, and they are willing to trust subordinates. They consider the development of future officers to be a great service. Such superiors accept the principle that one learns to manage by managing. They are accomplishing two important objectives: getting the work out and developing future officers. Errors that may occur are viewed in the proper perspective and minimized by precautions where possible.

A positive attitude encourages subordinates to accept responsibility. This helps them to become self-starters and to grow in the exercise of authority. Superiors need to study each subordinate, give him an appropriately expanding degree of authority, and hold before him the challenge of unusual accomplishments. The channels of communication must be kept open between superior and subordinate. The superior must be available but unobtrusive. He must firmly resist the temptation to

tell subordinates what to do and how to do it. A superior must exercise unlimited patience to put up with mistakes and fumbling and the slow acquisition of good judgment and leadership ability.

In vital phases of a fire operation, a chief officer may have good reason to show elements of the negative attitude toward delegation of authority, and he may wish to exercise very close supervision. However, in some types of overhauling work, with proper precautions in the form of unobtrusive supervision, the positive attitude is practicable. In addition, there are other phases of fire-department work, such as building inspection, where the positive attitude is not only practicable but advisable in the interest of officer development.

Two important issues face the manager who desires to delegate authority to a subordinate in order to give him managerial experience. The first issue is the degree of delegation to a particular individual, which should be characterized by a gradual expansion of the subordinate's authority. The second issue is the delegation of authority to several subordinates in different stages of development. The qualifications of the subordinate influence the nature and degree of the authority delegated to him. Those who have proved their capacity will be tested further by increased authority; those who have shown inability to use authority constructively will lose it. Some subordinates overestimate their ability as managers and, for this reason, resent what, in their estimation, is a limited degree of authority. With them the superior must demonstrate his sincerity and impartial intentions. There may also be subordinates who have proved themselves incapable of further development. The procedure in such cases is clear-cut. These men should not have been made supervisors in the first place, and there is no good alternative but to remove them from supervisory work, although this procedure cannot be resorted to in many fire departments because of civil-service regulations, political influence, etc. Extreme care should be used in selecting as supervisors only those who will prove themselves capable of further development; all others should be excluded from or removed from supervisory work. Having enjoyed the protective benefits of civil service during a long career, the author is reluctant to deny them to others; hence, he does not recommend demotion for apparent inferiority. He suggests, however, that civil-service examinations should be designed to facilitate selection of better officers with a minimum requirement of demonstrated desire and ability to assume responsibility. Without this qualification, promotion is a heavy burden to the individual and a decided detriment to his department, superiors, and subordinates.

Direction and Motivation. The superior who wishes to be successful in directing his subordinates must motivate them in ways that promote the accomplishment of unit and organization objectives. As a start, there-

fore, officers should themselves clearly understand motives and objectives.

Motives are basic drives, from satisfying hunger to improving financial, social, or educational status. Objectives are quite distinct from motives. Objectives are the targets whose realization will, in an individual's estimation, enable him to satisfy his desires. Thus a member of the fire service may strive for promotion (his objective) because he wants to improve his financial status (his motive) or to exercise the power such a position carries, or possibly to enjoy the prestige attached to a higher rank. The achievement of a single objective can in some cases serve to satisfy several drives.

Direction and Harmony of Objective. There is a need to bring into harmony the objectives of the individual and those of the unit and department so that the former contribute effectively to the latter. Difficulty arises from the fact that all subordinates need not have the same objectives. However, regardless of the objectives, it is the task of the officer to harness the efforts required to achieve them in a way that contributes to the department's purpose. Efficient direction clearly calls for the provision of goals whose achievement provides personal satisfactions for which men strive and at the same time accomplishes departmental objectives. For example, the head of the department might suggest to his subordinates as a worthwhile goal the attainment of a certificate of graduation from an especially designed course of study paid for by the community and intended to improve the quality of officers. This achievement would very probably yield personal satisfactions to the men, and at the same time efficient attainment of departmental objectives results. Graduates could be rewarded with extra credits toward promotion. The alert superior can both suggest goals and attach to them rewards for which men strive, thereby ensuring maximum harmony of objectives.

Direction and Discipline. Every officer is concerned with the quality of discipline that characterizes his subordinates because of its important bearing on the efficiency of his unit. Discipline, or orderly behavior, results from conformance with rules, procedures, and acceptable social practices. For example, it is important for subordinates to report on time, carry out orders properly, observe rules applicable to smoking, drinking, and dress, follow prescribed procedures, behave in a socially approved manner with respect to other persons, and undertake at least a minimum work load effectively. Discipline must be achieved in the interests of the future welfare of the department. It is fruitless for a superior to punish subordinates in a spirit of retribution or for the purpose of humiliating them. All disciplinary action must contribute to orderly behavior.

What factors affect the quality of discipline? A foremost factor is the

power of faith, described as the strongest disciplinary force in human history. It depends upon the quality of understanding by superiors and subordinates, as stated by J. D. Mooney: "When the laborer and the boss are bound by the same common understanding of some common purpose, the discipline is on a plane that no other form can reach." Branches of the American armed forces in World War II made excellent use of this idea by carefully explaining objectives and long-range plans of particular campaigns to the troops destined to carry them out. Experience clearly reveals that poorer discipline results from the "tell-'em-nothing" attitude. The practice of achieving a common understanding can be improved upon by pointing out, in addition, the advantages to subordinates of working for the enterprise objective.

A second factor is leadership. Subordinates are willing to follow or be guided by the example or persuasion of an effective leader. Obviously, officers capable of such leadership can develop the best type of discipline. When subordinates are willing to follow officers, there is a clear indication that they are being properly motivated; consequently, discipline problems will be minor.

The methods by which subordinates are disciplined are either negative or positive. Negative methods are usually employed. Although they may be necessary at times, they may have disadvantages. Negative methods, individually and together, fail to achieve proper motivation. These methods, which include such penalties as fines and transfers, may hurt the subordinate's family more than the man himself. In some cases he is penalized twice: once in the pay check and again in promotional exams, because his seniority may be adversely affected by fines. Negative methods imply coercion, and coercion is the least effective way of ensuring coordination in group activities.

Positive methods of discipline imply that rewards are given for good behavior, but this is not the case; the normal expectancy is that *all* subordinates will display disciplined conduct. Positive methods are those which can be effectively employed to maintain sound discipline with a minimum degree of force or punishment. They are designed to develop a tendency among personnel to avoid violations of rules and regulations and to meet the requirements of good discipline.

A Modern Disciplinary System. The objective of the system is to maintain and improve discipline to increase the efficiency of the unit. The relationship of discipline to conformance with rules, procedures, and acceptable social practices should be clearly understood. There should be no doubt about the importance of reporting on time, observing no-smoking and no-drinking rules, complying with regulations governing the use of uniforms, following official procedures, and meeting other obligations. A book or manual of regulations and procedure should be maintained

and each member given a copy; amendments or modifications should be made available promptly, and obsolete or unenforceable rules should be eliminated, as well as automatic and inflexible rules that operate unfairly and do not take into consideration individual circumstances. Rules that are frequently violated should be reexamined. Rules should be established, amended, or modified only after appropriate discussion and consultation. They should be formulated with recognition that members of the fire service today are better educated in democratic processes and are more conscious of, and sensitive about, the rights and dignity of the individual; firemen would be unhappy under a disciplinary system that ignored such a reality. Unhappiness promotes job dissatisfaction and impairs efficiency. Procedures should be analyzed at intervals and modified when found obsolete, duplicating, too complex, or too inflexible.

When violations are committed, subsequent action should be uniform. Major and minor violations should be clearly spelled out. Many minor violations can be handled at the company level if the defendant agrees, or he can insist on a board hearing. The penalties, if any, to be inflicted at the company level should be clearly specified.

Breaches of regulations should be acted upon immediately, and necessary papers should be forwarded promptly. Since endorsements by intermediate chief officers of the validity of the accusations have no legal weight but may be prejudicial, it is suggested that endorsements omit such opinions.

At trials, members of the fire service should have their constitutional rights safeguarded: the defendant should be allowed counsel, witnesses, and an appeal from the decision.

It is suggested that all ranks be represented on the trial board, whose chairman, however, should be a lawyer because of legal technicalities that may arise. A fireman can sit in judgment on a chief officer just as a clerk on a jury can sit in judgment on a bank president. The author favors a trial that is open to the public, despite some readily admitted unfavorable features. Trials should be conducted within fifteen days of the act in question, and as soon thereafter as reasonable, notes of the trial should be published and made available to all parties concerned.

The suggested system limits the use of negative techniques to a minimum, since they often emphasize punishment and humiliation and frequently prove fruitless. Positive methods will more certainly create an atmosphere that makes subordinates less likely to violate regulations. Every effort should be made to bring about the condition in which superior and subordinates are bound by a common understanding of a common purpose. This understanding is promoted when duly designated representatives of all ranks participate in formulating policies, rules, and procedures. Since all disciplinary action needs to be assessed by the

contribution it makes to improve the orderly behavior of subordinates, it is felt that a disciplinary system based on greater use of positive methods is desirable.

Training for officers should stress, among other things, techniques of reprimand and praise and leadership and morale in relation to discipline (when leadership and morale are high, disciplinary problems tend to decrease in number and severity). Fundamentally, the purpose of discipline is to train subordinates. Officers themselves should be so trained that they, in turn, can effectively train their subordinates to improve discipline and efficiency.

A board or committee should be established whose function is to disseminate awards to members whose efforts merit them. A rating system should be designed to ensure official appreciation in the form of aid to promotion, better assignments, and so on.

Direction and Leadership. Leadership is the ability to motivate people to think and direct their efforts as the leader desires. The nature of this ability is not clearly understood, and prolonged and extensive research on the subject is being done by various agencies. Much remains to be done, but there is universal agreement on one point: leadership is extremely important in any organization.

Leadership means a willingness of subordinates to follow or be guided by the persuasion or example of their leader. It has unique implications for members of the fire service since it is exercised not only in relation to duties of a nonhazardous nature but also in situations that may involve life and death during fire operations. Leadership in the fire service must be of a special variety in order to be effective, and certain qualifications have more weight in the fire service than in other fields. In this discussion, desirable leadership qualifications for fire officers are suggested.

Leadership is necessary because man is not self-sufficient. Many of his goals can be accomplished only through cooperative activity, for example, providing fire or police protection. Whether the functions of the contributors to group effort are specialized or not, only chaos results if there is no direction. Divisions of work, if any, need to be specified, and the several efforts must be properly timed. Even a team of horses works in unison only when there is a driver. Someone must make necessary decisions about the effort and its essential activities. Cooperative activity requires central management.

The terms *manager* and *leader* are often confused, but they are not synonymous. The manager coordinates the cooperative activities by executing the functions of planning, control, direction, staffing, and organizing. Since these functions are accomplished by other people, it is essential that the manager's subordinates be persuaded to carry out their duties effectively. For this purpose the manager employs leadership.

Thus, leadership ability is a vital factor in a manager's success. In addition, he requires the ability to understand and carry out his managerial functions as well as sound judgment, initiative, and integrity.

The basic problem of leadership is to develop skills that constructively influence subordinates to achieve specific goals. To be good leaders, officers need to understand themselves, their subordinates, the situation in which the group operates, and the communication techniques through which influence is exercised.

Helpful understanding is obtained from the fact that in recent decades psychologists have classified the ever-present needs of superiors and subordinates as physical, psychic, and social. They have identified some of the specific needs in each classification, such as protection, shelter, and convenience; curiosity and intellectual attainment; and friendship, good will, and appreciation. Officers would be ineffective leaders if they failed to take these elements into account in the process of influencing others. The situation in which the superior and his subordinates operate has static as well as dynamic characteristics, all of which influence the officer's choice of leadership techniques. The layout of a department, the work sites of subordinates, and the nature of the work are all important static factors. Changes in the nature and scope of work, in the competitive situation, and in the drive associated with the work (as at fires) illustrate the dynamics of the situation. To be effective, officers should influence their men to act cooperatively and in a timely fashion to accomplish the group objective. Both negative and positive types of motivation are used. Negative motivation includes imposition of fines or extra duty, transfer, dismissal, and, demotion. Generally speaking, negative motivation deprives people of the satisfaction of their physical, psychic, and social needs. Positive motivation rewards "correct" behavior by offering satisfaction of needs.

Leadership is interpersonal influence exerted through communication. Direction of subordinates basically constitutes a problem in communication. Good communication is based on a sensitivity to the personality of others and a conscientious effort to understand their assumptions, attitudes, and behavior. Once understanding is achieved, the leader can select the most effective means for communicating with group members. The ability to listen is essential for proper understanding.

At present, there is no basis for evaluating leadership characteristics. However, many believe that there is a high degree of transferability of leadership skill from different enterprises. Good leaders are believed to have above-average mental ability, a desire to lead, and several helpful personality factors. If enterprises are similar in nature, a leader should be able to transfer his skills because he should understand the problems, attitudes, and needs of subordinates as well as the group situation. He

would be able to employ proper persuasion to motivate subordinates successfully. Thus, the leader of a large-scale enterprise should be able readily to transfer to other large-scale enterprises. However, the leadership characteristics of the head of, say, a labor union might very well be ineffective in an educational institution; a union leader might be handicapped by inability to understand the problems, attitudes, and needs in the new situations. There are necessarily limits to the extent to which a leader can transfer successfully from one organization to another.

The influence of a top leader filters through an organization, touching each member and largely accounting for the reputation of the organization. A leader gives tone to the enterprise by the way he employs motivation. Organizations with skilled leadership are known by the quality of people who want to belong, the high spirit of cooperation among members, and the respect of responsible elements in society. The permeating effect of leadership is not always a blessing, however, since the effect is felt whether the leadership is good or bad.

The *responsibilities of leadership* are comprised of the obligations owed to the enterprise and to society. Managers at top levels are obliged to act with both integrity and efficiency to coordinate teamwork among subordinates to achieve the enterprise objective. At fire operations, the commanding officer, generally speaking, achieves teamwork by clearly defining the objective (rescue work, direct extinguishment, or confinement, control, and then extinguishment), deciding on essential activities, assigning appropriate activities to incoming units, and supplying adequate supervision and communication. Officers at lower levels should seek the accomplishment of their unit or department objectives in order to contribute maximally to the total purpose.

In the old days, different fire companies arriving at a fire would fight each other for the privilege of putting it out—while the fire, of course, burned merrily. This no longer happens because modern fire personnel are more conscious of the primacy of the enterprise objective at a fire. Officers can do much to ensure that unit objectives do not clash by (1) forcing entry in a timely manner, with ladder and engine companies cooperating; (2) ventilating the fire area effectively so that the ladder company aids rather than hinders the engine company trying to advance a line and put the fire out; (3) avoiding the use of opposing lines, each of which defeats the purpose of the other; and (4) selecting hydrants so that water is not taken from a working line of another unit, etc.

The officer, as a leader, has a definite obligation to society. He has a moral responsibility to select enterprise objectives and employ techniques that are consistent with the general welfare. He is not free to adopt an objective that will result in fraud, endanger health, or infringe upon the rights of others, nor may he select methods of motivation that

are detrimental to the objectives of society. Hence integrity is essential.

Certain leadership characteristics can logically be suggested as particularly appropriate for officers in the fire service. These suggestions are based primarily on the modern concept that leadership implies a *willingness* on the part of subordinates to follow or be guided by persuasion or the example of the leader.

Fire officers require better than average intelligence to understand and solve complex problems. They must have proper psychological insight into problems, needs, and attitudes of subordinates and also into the group situation. In short, officers must have understanding.

They must also be good listeners. Understanding an individual and his ideas requires not only close attention to what he is saying but, more importantly, the capacity and willingness to see and understand his viewpoint.

The ability to maintain effective communication is important, keeping it in mind that the real test of communication is the extent of the recipient's comprehension of what was meant to be conveyed. Experienced officers realize the importance of this, particularly during the early stages of a complex fire operation. Some subordinate officers appear to be listening to an order (even a brief one), but because of excitable temperament they actually hear only part of it; others are inclined to rush off before receiving necessary instructions. To offset possible misunderstanding, the commanding officer might ask the subordinate officer one or two pertinent questions about his assignment.

The importance of communication cannot be overemphasized, since leadership has been defined as the ability of an individual to exert interpersonal influence toward the achievement of a goal through the medium of communication. Unusual verbal facility unquestionably is a helpful characteristic, since language is an important part of communication. Verbal facility will help reveal to subordinates that the leader possesses two very essential traits of a fire officer: (1) knowledge of the job and (2) concern for the welfare of subordinates. Men will be more willing to follow or be guided by such an officer.

Officers must show good judgment. They should habitually practice care in recognizing and evaluating all the factors in a given situation and should assess these factors in the light of the total environment. They should take sufficient time to reach a decision and should make commonsense decisions, which are implemented at the proper time.

Leaders in the fire service should show emotional stability, enthusiasm, and persistence, and they should be accessible to the men. They should instill in members a keen appreciation of the service traditions, history, objectives, and policies. They must know how to praise, reprimand, give orders, train members, and, particularly, stimulate their improvement. They must not only know alternative means of dealing with members

but have the ability to employ the right one at the right time in the right way. Coaching subordinates to develop and maintain effective teamwork is also important, as is handling men in a manner that gives recognition to the individual, giving fair and impartial treatment, being ready to listen to grievances and suggestions, and keeping men properly informed.

The desire to lead is an essential characteristic since those who lead with reluctance do an inferior job. Leaders must also recognize the primacy of the objective of the fire service and be aware that they have a definite responsibility to society and to the service.

Subordinates will more likely be willing to follow or be guided by officers possessing the foregoing traits.

Direction and Morale. Where morale is high, subordinates work with assurance, attack the job with vigor, have confidence in their own ability and in that of their co-workers to achieve a given objective, and show effective teamwork. Morale is a pervasive quality. Its fundamental basis is personal faith. It can be observed clearly in times of adversity, and it does not depend upon favorable conditions. Napoleon said of morale: "In war, morale conditions make up three-quarters of the game: the relative balance of manpower accounts for the remaining quarter."

Morale in the fire service, as in other organizations, is influenced by managerial skill, leadership, the type of communication and discipline used, and the consideration given to the welfare of personnel. The democratic background of American firefighters must always be kept in mind. Recognition of and respect for the rights of all members is important.

Suggestions for Improving Morale

1. Personnel should clearly understand the dominant goals of the unit or department, because the best coordination occurs when individuals see how their jobs and their goals harmonize with enterprise goals.

2. Both superiors and subordinates should understand the nature of management. Then officers can perform supervisory work more effectively and not waste time and effort on nonsupervisory work. Proper understanding by subordinates enables them to appreciate the managerial skill of their superiors, which will improve cooperation between subordinates and superiors.

3. When planning, the officer should keep personnel informed within reason about present and future plans, policies, and procedures. He should utilize adequate advisory groups to keep abreast of new problems and solutions and inform personnel as deemed advisable. He can utilize a suggestion program to foster the feeling of participation in the plans of the organization, and he can specify the method for modifying policies and procedures in order to avoid confusion and accelerate action.

4. When organizing, the officer should pay careful attention to the

principles of organization in order to produce a structure in which the functions and authority of units are clearly defined and whose framework facilitates the desired correlation of activities. Such a structure will improve efficiency and morale. Authority delegated must be commensurate with the responsibility involved, and delegations should be as clear and specific as possible to avoid uncertainty and overlapping. Unity of command aids the subordinate, because he knows from whom he is to receive orders, and it aids the superior, who knows better than anyone else how to motivate his subordinates. Appropriate decentralization of authority is advisable, because it is conducive to the development of leadership and morale.

5. Supervisors should see that their subordinates are achieving a high degree of coordination among themselves and with other units. Coordination must be achieved by the proper use of principles and techniques (Chap. 15).

6. When staffing, officers should select recruits through better exams, personal interviews, and character investigations. Adequate salary should be offered to attract good officer material and to obviate the need for two jobs. Dual employment is accompanied by dual responsibility, which impairs morale.

A probationary period should be set up for screening out the unfit among those who passed preliminary tests. Training programs should be modernized to improve the quality of officers and should stress leadership and management. Improving the quality of officers will tend to improve morale. Promotional exams should be held more frequently. This would stimulate effort and ambition. Seniority ratings should not be adversely affected by fines imposed for infractions of regulations.

In connection with staffing, high-ranking officers of the fire service should know the essential qualifications for officers of various ranks and should devise ways and means to discover these qualifications. The heads of many large fire departments are not delegated commensurate authority in this matter. They should be delegated authority to specify the type of examination and the sources of information to be used in promotional examinations. Since fire department heads are responsible for effectively preventing and extinguishing fires, they should have some authority in the selection of officers by whom the jobs are done. This suggestion in no way reflects on civil-service commissions, which in most cases do a good job under definite handicaps.

7. In carrying out the function of control, fire-department heads should consider setting up adequate control processes for such important activities as fire prevention. A major difficulty is the establishment of standards. Helpful research may overcome this difficulty. The following suggestions are offered for a fire-prevention inspection control device, which may

contribute to the attainment of enterprise objectives in fire prevention and thereby improve morale.

a. Establish a budget for each occupancy. This is a statement of anticipated results at future inspections, expressed in terms reducible to numerical expressions such as man-hours spent on each inspection, number and kind of violations found, attitude toward compliance with orders issued, and number of summonses issued. In the initial stage, the budget will perhaps be far from accurate, since it may be based on surmises. It may take four or five years before a budget based on data derived from inspections made during that period represents a true statement of what can be expected at the next inspection. Standards can then be established, taking into account seasonal variations in businesses.

b. IBM machines can be used to compile data for effective analysis. Results of subsequent inspections can be compared (on a spot-check or other basis) for appraisal of performance. Where inspection reports give a clean bill of health to occupancies whose budgets indicate a record as chronic violators, a check is warranted, which may reveal that the inspection was inferior. Correction of inspection technique (in the form of additional training and supervision) may then be in order. The budget has additional benefits because the comparison of inspection reports may reveal a tendency in occupants to let down in fire-prevention practices. Deviations should be corrected promptly by fire-prevention education, more frequent inspections, or continued surveillance. The suggested budget provides controls for both the inspector and the inspected. Such budgets must be accessible only to supervisors.

c. The program might best be started with one type of occupancy. Other occupancies could be included later. The program could be established on a limited scale if desired, emphasizing target hazards. A budget would scarcely be necessary for average occupancies in fireproof office buildings. Naturally, the expected results and standards will vary with time, since improvement will reduce the number and seriousness of violations. This tendency should be reflected in the budget.

d. Measures should be taken to eliminate or reduce unfavorable time lags between inspections. In some departments, units may take more than a year to complete their circuit of inspections. It would be beneficial if this span could be reduced to nine months or less. Units with comparatively minor work loads might be relocated at times in the quarters of units requiring more time for inspection.

8. Communications play an important part in morale. Avenues of communication should be kept open between management and personnel and between superiors and subordinates. Superiors are more likely to be successful if they can develop in subordinates the attitude that the boss is an aid rather than a threat.

9. An effective disciplinary system, as previously described, should be maintained. An effective rating can be established to provide rewards and to check against inefficiency. Rewards that may *favorably* affect seniority ratings in promotional exams are advocated because all personnel have an equal opportunity under such a system and because such a feature will tend to contribute more to discipline and morale.

10. Conditions of service, such as vacations, sick leave, transfers, hours of work, and physical surroundings should be regulated to convince personnel that constant care is being exercised for their welfare. An effective accident-prevention program is desirable, with adequate supply of masks and as many welfare benefits as possible and practical (blood donor, ambulance, dental care, etc.). Personnel should be informed how benefits can be obtained. The purpose in providing the above benefits is to satisfy the personal needs of the men in such a way that it contributes to the achievement of enterprise goals.

11. A public-relations program should be set up to inform the public about fire-service activities and increase public cooperation. Such a program is a kind of communication, and, as such, it has an important bearing on morale.

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Issuing Orders

An order is an important device of direction. It is the specific means by which an activity is initiated, modified, or stopped, and it may be defined as the command of a superior requiring a subordinate to act or refrain from acting in a given situation. This definition implies an interpersonal relationship between a superior and a subordinate and a direct line of command from the former to the latter. This relationship is not reversible, nor can it exist between officers of equal rank. The subject of the order must pertain to activities connected with achievement of the enterprise objective. An order must be enforceable. An officer's position would be untenable if he could not employ sanctions against subordinates who either refuse to carry out orders or carry them out inappropriately.

General or Specific Orders. Whether an order is specific or general depends on the superior's preference, his ability to foresee all the circumstances that accompany a given activity, and the response made by the subordinate. Superiors with a negative attitude toward delegation of authority seem predisposed to specific orders. They evidently feel that they have clearly in mind what has to be done and the best way to accomplish it. In addition, they want tasks done in a certain way and prefer to direct their subordinates very closely.

Where it is not possible to foresee all the attendant circumstances that may influence the way in which an activity is undertaken, orders are more likely to be general. When the task is accomplished far from the personal direction of the superior, no effort should be made to give specific orders. Thus it is that at fire operations orders are often general,

such as "open up the roof," "get everyone out," and "check the rear." It would be difficult and actually unwise for a commanding officer to attempt to give specific orders where he cannot possibly foresee all the problems.

A subordinate's response to an order influences the nature of orders given to him. Some subordinates actually prefer close supervision and consequently do well with specific orders. Others, however, chafe under such conditions and prefer to exercise their own initiative and creativeness; they are quite willing to be judged by the results.

Orders at fire operations are often given in general terms both because the commanding officer has no time to state specifically how the order should be carried out and because general orders convey sufficient information in view of the training of firefighters. This is the case even where life hazard is involved. For example, at a fire involving the top floor of a five-story residential building, the superior officer may order the officer of the first engine company to arrive: "Take your line to the top floor." Obviously, he does not have time to specify what hydrant is to be used, what engine pressure is required, the number of lengths in the line, the type of nozzle to be used, the nozzle pressure, etc. And in view of the subordinate's training it need not be specified that the line should be taken up the inside stairway, that its purpose is to cover any possible life hazard, and that therefore it should be operated as quickly as possible between the endangered occupants and the fire. Even with general orders, supervision should be as close as necessary to ensure that the objective is attained and to supplement or modify the order as required.

Written or Oral Orders. Whether an order is written or oral depends on several considerations. The permanency of the relationship between the superior and the subordinate has an influence. If the relationship is continuous, it is often unnecessary to reduce orders to writing. However, because of the high degree of mobility in agencies such as military forces or the fire service, it is both unsafe and unwise to operate without written orders, at least concerning duties that pertain to the job rather than to the man and duties that take considerable time to accomplish. Such orders are essential in the fire service for detailed officers and for officers of relocating companies where the units covered have special assignments.

The quality of trust between superior and subordinate is also important. Subordinates, feeling that the major risk in the superior-subordinate relationship is carried by them, may prefer the protection of a specific, written order. Written orders tend to prevent overlapping of assignments. They are the best means of achieving uniform adherence and tend to prevent jurisdictional disputes. It is often helpful to inform

all affected personnel of a particular assignment by publishing a written order if the assignment exceeds usual limits. Without such a communication, the undertaking may meet resistance, sabotage, and general lack of cooperation. Lengthy, detailed, and complicated orders should be written.

Techniques of Issuing Orders. As much information about an order as possible should be passed on to subordinates on the sound assumption that men who know the reason for an order are more easily and effectively motivated than those who are uninformed. Good coordination helps in issuing orders because it facilitates teamwork. This means that officers should give the matter of timing appropriate attention. Officers who employ these steps are dealing more effectively with subordinates. Using these techniques, however, is a continuing, and not a self-perpetuating, job, and they can never be safely ignored.

Subordinates recognize that some information must be classified, but they tend to become disinterested or dissatisfied when a superior either fears or neglects to communicate nonconfidential information that would enable them to understand new decisions. In some instances, even confidential information can be passed on to subordinates with good results. The superior who explains the background of decisions to subordinates has a strong appeal for members of the fire service in the United States and other democratic countries. This is due, in part, to higher educational levels, more widespread belief in democratic processes, and increased insistence that human dignity be respected.

Superior officers should be aware that lower- and middle-level officers may have more formal education than they themselves do, that many officers know something about group power in the democratic process, and that an increasing number are familiar with the importance of human relations. These men are very likely to resent any dictatorial attitude on the part of superiors.

Regardless of the educational level of subordinates, the following advantages result when they understand the background of decisions: when a man understands the reason for a course of action, he sees why it should be done in a certain way and this eliminates unnecessary resentment; only when a subordinate officer understands as thoroughly as possible the reasons for an order can he make his own plans in the most effective and efficient manner; proper understanding tends to improve morale.

The superior who makes certain that his subordinates understand the different types of authority can eliminate many difficult situations. It is not merely a matter of showing subordinates the organization chart and enumerating assigned duties and delegated authority; the superior must differentiate for subordinates the various types and reaches of authority

and teach them the kinds of behavior appropriate to each. Officers with line authority often fail to understand that it penetrates only to their immediate subordinates and not to the subordinates of men who report directly. For example, the battalion chief to whom a company officer reports has no authority over the latter's subordinates. They, like everyone else, are always subject to applicable department rules and policies, but beyond this they properly look to the company officer for direction. The difference between line and staff authority is also a potential cause of trouble. It is important for a man to know when he has the authority to command and when he can only advise. Subordinate officers need to know not only which type of authority they possess but which type is possessed by other officers. Subordinates in staff units should be instructed carefully about the nature of their dealings with personnel in other units. They should realize that their usefulness depends upon the effective advice they can give to other departments or units, preferably upon request. On the other hand, subordinate line officers should be carefully instructed to request staff advice freely and fully and to listen to it.

No officer is ever free to violate a policy, ignore a procedure, or modify a program. Changes may be made, of course, but only by due process. Superiors, therefore, must present policies in the most clear-cut and understandable terms when such policies are sufficiently important.

In the ordinary process of devising new programs, there are inevitably ambiguities, contradictions, and possibly costly practices. As a result, officers frequently feel frustrated and they are inclined to cut corners, to reinterpret policies, or to suggest immediate changes. Procedures for suggesting changes should be stipulated and made known. Subordinates should be encouraged to discover and report the need for changes.

There are three broad classes of supervisory techniques: *consultative, autocratic,* and *free-rein* methods.

Consultative Methods. Superiors encourage maximum participation by subordinates in matters that pertain to departmental or unit functions. They should be eager to adopt suggestions if they have merit. The important points of consultative methods are the democratic behavior of the superior, his sincerity in implicating his subordinates in departmental plans, and his emphasis on group action. Conferences are a basic tool for the transmission of information and understanding. *Informal* conferences, called on the spur of the moment, can be extremely useful. They may deal with problems of securing better coordination between subordinates or between subordinates and personnel outside the unit, involve discussion of new policies, interpret new information or clarify existing policies, procedures, and programs, consider current programs and bottlenecks and potential countermeasures, and transmit first-hand informa-

tion to the superior. Informal conferences are effective because participants tend to trust and respect each other and have a sense of their combined effectiveness. They are called only when the need arises and are attended only by those affected, thus minimizing the time involved.

Formal conferences require written notification of the time and place of the meeting and possibly the transmission of the agenda. Subjects might include the impact on the department of the threat of war, explanation of new official policies and programs, clarification of established policies and procedures, explanation of changes in the organization structure, and information about the status of programs. Formal conferences are called when the need arises and are not held without a specific purpose. The scope of the conference depends upon the persons affected.

Fundamentally, formal conferences permit information to be dispensed and questions to be asked. They have the superior effectiveness of direct communication.

Although consultative techniques are usually applied to groups, they may also be used to direct individuals. The superior who asks for advice on a course of action, who persuades, or who welcomes suggestions from individual subordinates is using consultative techniques. They are effective because most people dislike being ordered about and feel a sense of importance when their suggestions are solicited and considered. Consultative methods are particularly effective in acquainting subordinates with superiors far removed in status. Participating subordinate officers, seeing and hearing top-level superiors, acquire an understanding of departmental problems and policies and of the forces that determine the decision. Some personal knowledge of high superiors has a powerful humanizing and helpful influence.

The disadvantages of consultative methods result largely from their misuse. Subject matter must be appropriate. Skill is required to achieve the desired result. Any hint of autocracy, destructive criticism, lack of respect for members, or secrecy will nullify the effectiveness of these techniques. Moreover, the superior needs leadership ability, teaching skill, and the conviction that participation pays off.

Autocratic Methods. These techniques develop naturally from a superior's belief that he should assume full command over all actions by subordinates. Actually, such a superior may believe that subordinates cannot be trusted to act for themselves. The source of this conviction may rest in the personality of the superior or in his experience with subordinates whose lack of education and training make an autocratic approach necessary. Autocratic techniques are characterized by retention of power by superiors, reliance upon specific orders, and maintenance of close supervision. Superiors who choose to direct subordinates in an autocratic manner generally have a negative attitude toward

delegation of authority. They are most likely to rely upon formal orders instead of more informal techniques. Autocratic methods carry overtones of marked superior-subordinate relationships, continually reminding subordinates who is the boss. However, these methods can be very effective in getting action from subordinates who tend to avoid responsibility.

Autocratic superiors usually give detailed instructions. In some cases, this is appropriate, since many jobs can be accomplished in one best way, particularly those studied by time-and-motion experts. Likewise, at a fire operation, the assignments may allow subordinates no room for personal predilection. However, where officers are qualified to carry out assignments, they will be quick to resent minute and specific instructions. Nothing kills initiative and productivity as quickly as detailed instructions.

Close supervision may be related to the superior's basic lack of trust, but at a fire operation such supervision is not only justifiable but strongly advisable, particularly where there is a life hazard for occupants or fire personnel. Such assignments at fire operations require close supervision so that orders can be modified, supplemented, or countermanded promptly. Hence autocratic methods may be appropriate at fire operations, and they may be advisable in dealing with timid, uneducated, or hostile persons. Where strong leadership can bring order out of chaos, a superior may find that a positive outlook and heightened morale result from the firmness and definiteness of autocratic techniques.

Free-rein Methods. These techniques are characteristic of superiors who have a positive attitude toward delegating authority. Such techniques emerge when individuals are encouraged to develop and contribute independent thought and action to the attainment of unit objectives. Free-rein methods are especially useful in developing officers, since experience in decision making is essential. With free-rein methods authority is delegated willingly, instructions are general, supervision is unobtrusive, there is open-door communication, and past decisions are analyzed. Where authority is delegated willingly, subordinates, anxious to take advantage of the opportunity, respond with their best efforts and will be careful not to let their superior down. This technique has some disadvantages because of the time taken to reach decisions and possible fumbling and wrong decisions.

General rather than specific assignment of duties compels the subordinate to think for himself. He grows in self-reliance and assurance, finds application for new ideas, and develops sound judgment. Interference is kept to a minimum, but superiors keep their eyes and ears open and move about their units to give adequate supervision. When the need arises, they can pinpoint their observations and exercise their

supervisory powers by talking over problems and reviewing the work of individual subordinates. The superior must keep himself available to his subordinates, but initiative is left to the latter to seek the superior and clarify ideas. The function of the superior here is to act as a sounding board, to make suggestions from his personal knowledge and experience, and to clarify the alternatives open to the subordinates, but he must refrain from telling the subordinate how to proceed. Accomplished assignments are reviewed with the subordinate to evaluate results. In these discussions all matters are approached objectively. Criticism of the subordinate is avoided, except when he sees and criticizes his own mistakes.

Free-rein methods can be extremely effective in supervising more highly educated subordinates. They must be used between superiors and subordinates who are psychologically adjusted to freedom. Subordinates can flourish and develop most effectively with these methods when they have a high standard of education, are strongly committed to democratic methods, are gifted with more than average initiative, are ready and eager to accept the responsibility associated with advancement, and are inclined to resent what they consider unnecessary close supervision and specific orders. Supervisors using these methods must have immense patience, teaching ability, and forbearance.

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Planning and Policy Making

Steps in Planning. These steps, while presented in connection with major programs, nevertheless must be followed in any thorough and logical planning.

The first step is the establishment of objectives. Subordinate objectives may require subordinate or derivative plans. The primary objective at a fire operation may be to protect endangered occupants. Derivative plans may then have to be formulated for ladder companies to ventilate specified areas, raise ladders, and search for and remove occupants and for engine companies to place and operate hose lines so that such units can contribute their maximum effort to achieve the primary objective.

The development of planning assumptions is the second step. Assumptions are based upon data of a factual nature and will indicate the basic policies and procedures applicable to a contemplated fire operation. They are the setting against which further planning takes place. It is comparatively easy to solve problems as they arise, but it is very ineffective and inefficient at fire operations. Planning, to be adequate, should prevent problems if possible and anticipate those that are inescapable so that proper countermeasures can be planned.

Planning is greatly simplified if a method can be devised to expedite the development of accurate assumptions, as, for example, the approach outlined in Chap. 4 and the plan of action outlined in Chap. 9.

Forecasts must relate to anticipated problems, such as problems of fire

incidence, apparatus, equipment, personnel, water supply, and shifting population and industry or, at fire operations, problems of rescue, ventilation, selection of extinguishing agents, and placement and use of lines.

Three types of factors influence planning assumptions. Some factors are noncontrollable: the fire department can do nothing to prevent these factors from affecting planning assumptions. Noncontrollable factors include population growth, business cycles, construction trends, political environment, and wartime conditions. At fire operations weather, wind, time, construction, location of fire, type of material burning, and extent of the fire when the fire department arrives are noncontrollable factors.

Other factors are semicontrollable: fire departments cannot control them but can influence them to some degree. A safety program, for example, cannot prevent accidents, but it can influence accident incidence. The fire department cannot stop individuals from smoking in bed, but it can influence the public on the matter through an educational program.

Still other factors are controllable: the fire service can largely decide for itself matters pertaining to internal policies, procedures, and programs. At fire operations, the commanding officer decides upon the objective and the policies and procedures by which it is to be achieved.

The third step in planning is to search for and evaluate alternative courses of action. In most cases, reasonable alternatives do exist. Evaluation involves weighing the various factors and selecting the alternative that offers the best probability of achieving the objective within the limits of reasonably acceptable risks. Evaluation is difficult if the planning problem is full of uncertainties.

The fourth step is to select a course of action. This is the point of decision making (see below).

The final step is to formulate necessary derivative plans. Basic plans are not self-achieving. They must be broken down into further plans, with units executing subsidiary plans in order to accomplish the basic objective.

Decision Making. Decision making is the culmination of the planning process. Decisions are made when superiors select basic objectives, choose policy, or determine strategy just as surely as when they establish procedures, initiate programs, or formulate budgets. A course of action does not have to be carefully thought out or applicable over a long period of time in order to be a plan. Even the briefest fire operation may require the commanding officer to make several decisions, thereby involving the planning function. Naturally, more complicated fire operations call for more carefully and completely developed plans, but in either case planning is involved. Each decision involves the same process of choosing a course of action from among alternatives, regardless of the level at which the choice is made.

It does not necessarily take long to make a proper decision. If the decision-making process is properly understood and practiced, all the elements can be combined almost unconsciously and the decision arrived at quickly.

Decisions must always be based on good judgment (Chap. 16, Leadership). Officers who make an intelligent effort to develop good judgment will definitely improve their decision-making ability. However, good judgment is not infallible, and decision making will always entail risks. Risks can be minimized by applying the following steps:

1. Define the problem.
2. Establish specifications for an acceptable solution.
3. Define expectations about the objective.
4. Define alternate solutions.
5. Make the decision.
6. Convert the decision into action.

A tool that in the great majority of cases enables an officer to define the problem is critical-factor analysis. The critical (or limiting) factor is the element in a situation that must be changed, moved, or removed before anything else can be done. By isolating this strategic element, an officer can usually come to grips with the problem. Many examples of the strategic factor can be given. If an automobile is in good condition but lacks gasoline, the critical factor is obviously gasoline. At fire operations, the critical factor may be rescue work, forcible entry, ventilation, water supply, equipment, manpower, equipment, or heavy-stream appliances. During an apparatus-replacement program, the limiting factor of capital availability may be resolved only for a different limiting factor to appear in the form of delivery of apparatus or training of operators. The approach to fire operations discussed in Chap. 4 facilitates discovery of limiting factors.

Time affects defining the problem: it is essential to know when the problem has to be solved and when decisions have to be made. There is no point in making a decision before it can be effective, for example, calling a searchlight apparatus two hours before dark, but on the other hand, procrastination should be avoided. A decision about a second hose line, for example, should be made as soon as its potential need is recognized and not after the need has become an actuality.

Establishing specifications for an acceptable solution involves correlating the objectives sought and the risks involved. The objectives at a fire operation could include rescue work, fire extinguishment, or confinement, control, and then extinguishment. In general, there are no riskless decisions, but obviously the risks must be limited. Greater risks are generally taken at fire operations to rescue endangered persons. However, where conditions clearly indicate that rescue is impossible, the risks taken by

fire personnel will be limited rather than needlessly and uselessly increasing the casualty list.

Defining the expectations of a decision is a mechanism for later review and improvement, which may include modification of plans. It emphasizes the importance of getting appropriate information and focuses attention on the fact that information is more available in some areas than in others, necessitating some guesswork and surmises.

At first glance, developing alternate solutions may seem to be an impractical consideration at fire operations because of pressing time. Actually, however, company officers consider alternatives from the time they leave quarters in response to an alarm until they return. The choice of route to be taken, hydrant to be used, size of hose and size and type of nozzle used, type of mask required, where to stretch and operate hose lines, whether to initiate an interior or exterior attack, and whether to use booster equipment or hook up directly to a hydrant—all require selecting among alternatives.

Making sure that all the alternatives are considered is necessary because normally an individual sees only what he expects to see, and therefore he tends to overlook the possibility of unexpected developments. Lack of imagination rather than of intelligence increases problems in decision making. Considering practical alternatives is a better way to make sure that opportunities are not overlooked.

Making a decision follows the examination of alternatives. The range of actions available is compared against the specifications established. This does not automatically supply the right decision. It is rare to find a situation in which any of the available actions is perfect, and there are no situations that are riskless. Hence good judgment must be used to choose the course of action.

Unfortunately, those who make decisions are not always those who carry them out. It is important, therefore, to make sure that decisions are understood by the people who carry them out, to know who those people are, and to acquaint them with necessary details of the action plan. Skillful organization, direction, staffing, and control are, of course, essential to converting decisions into action.

Policy Formulation. Policy formulation plays a major role in planning, but it is not the whole of it. Policies point the way to the development of plans, the solution of problems, and the attainment of enterprise objectives. In a sense, policies are guides that lead to operational plans.

Policy is normally made at all levels in an organization, but obviously officers at higher levels play a more important role in policy making than those at lower levels. There are three types of policy: originated, appealed, and imposed.

Originated policy is perhaps the most significant type. It is originated

by officers expressly to guide themselves and their subordinates and flows logically from the objectives of the organization as defined by top-level authority. Original policy may be broad in scope, allowing key subordinates to define it more clearly, or it may be specific and narrow in scope. The establishment of clear policies is one of the best means by which the top executive can delegate authority and still maintain control. Policies must be consistent and integrated in such a way as to contribute to the achievement of the enterprise objective.

Appealed policy is, in effect, policy by precedent. It comes from the appeal of exceptional cases up the hierarchy of managerial authority. An officer may appeal to his superior because he does not know whether he has the authority to make a decision or does not know how a matter should be handled. Obviously, such appeals apply only in a very limited way at fire operations because of the time element. As these appeals are taken upward and decisions are made, a kind of common law is established in the organization. Precedents develop and become guides for later action. There is a danger that such policies will be incomplete, uncoordinated, and confused.

Policy formulated from appeals will be foresighted and internally consistent if the superior realizes that his decision constitutes policy. However, where a superior finds himself constantly making policy by this process, he might well ask himself whether he has left too large an area of policy making to chance, or whether subordinates understand the policy he has formulated.

Externally imposed policies result from outside forces, such as wartime government regulations restricting the use of gasoline, a severe snowstorm drastically interfering with response of apparatus, disrupted water supply as a result of a bombing attack, the effects of collective bargaining, and the efforts of social, religious, fraternal, charitable, or educational groups. External forces affect policy making in two ways: sometimes they dictate specific policies; sometimes they create conditions that mold managerial decisions.

Policies Relating to Managerial Functions. Policies may be formulated about (1) planning (the length of time for which to plan, the amount of detail or thoroughness of plans, the extent of organizational participation in planning, and the desired degree of flexibility), (2) organizing (the span of management or control, the degree of dispersal of authority, how to maintain some centralized control when authority is decentralized, and clarification of functions and authority), (3) staffing (selecting, recruiting, training, promoting from within or otherwise, hiring the man to fit the job versus modifying the job to fit the man, the use of rating systems, and seniority and other ratings that affect eligible lists), (4) direction

(attitudes toward delegation of authority, discipline, leadership, morale, communications, issuing of orders, the techniques of direction to be used, and the emphasis on human relations), (5) control (where in the organization special kinds of controls shall be applied, whether budgetary control devices shall be used, the length of time in the future to be considered, and the amount of detail).

Policies Relating to Organization Functions. Policies may also be formulated in relation to the objectives of the fire service (fire prevention and protection of life and property against fire) and to practically all phases of a fire operation.

Numerous policies could be formulated about ladder work. To what extent should fire buildings be laddered? When should aerials be raised to the roof? What use should be made of aerials at oblique angles. Various policies are also formulated about nozzle size and type and how to place and use lines. Other policies affect when, where, and how to ventilate and overhaul.

Policies have been formulated to guide officers in initiating interior or exterior operations. The foremost policy of the fire service dictates that an interior attack should be attempted in the interest of rescuing occupants if it is at all possible and practical. Where there is no life hazard to occupants, the dominant policy is that fire personnel are not to be jeopardized unnecessarily for the sake of property alone. Policies can be formulated about how and by whom salvage is to be carried out, about types of mask to be used and procedures for using them, and about communications devices. Policy can be formulated about additional phases of fire operations, such as orders given at fires, supervision, selecting hydrants, covering exposures, relieving men on lines and elsewhere, overhauling, street conditions, and public relations.

An understanding of what policies are as well as the grounds upon which they are formulated will enable officers to create and employ policies that will be practical and durable. The adherence to policies has such a profound effect upon the achievement of goals that detecting signs of policy failure requires prime consideration. The number and type of appeals for policy modifications may reflect failure. Evidence of conflict between department policy and the rules of society may indicate failure. For example, the policy of right of way for fire apparatus, as originally employed in some communities, was found to conflict with standards of public safety. Hence, the policy was modified: fire apparatus must slow down and be ready to stop if necessary to avoid an accident when approaching intersections, regardless of whether the traffic light is red or green.

A third means of detecting policy failure is to evaluate the results

against logical expectations. This is part of the control process. The development of effective control devices would naturally assist in policy formulation and application.

Communication of policy helps provide the common understanding so beneficial for securing conformity and consistency in interpretation. Historically, there has been a long tradition of unwritten policy. The author strongly advocates that broad guides for the fire service as a whole and for component units should be written down. This book constitutes to some extent an enumeration and explanation of fire-service policies, with the hope that constructive study and criticism may result to the ultimate benefit of the men in the fire service and of the public they serve.

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